Two new scopes honor astronomers **Vera Rubin** and **Nancy Roman** p. 24

APRIL 2021

Astronomy

The world's best-selling astronomy magazine

ROGUE PLANETS

What interstellar travelers tell us about the galaxy

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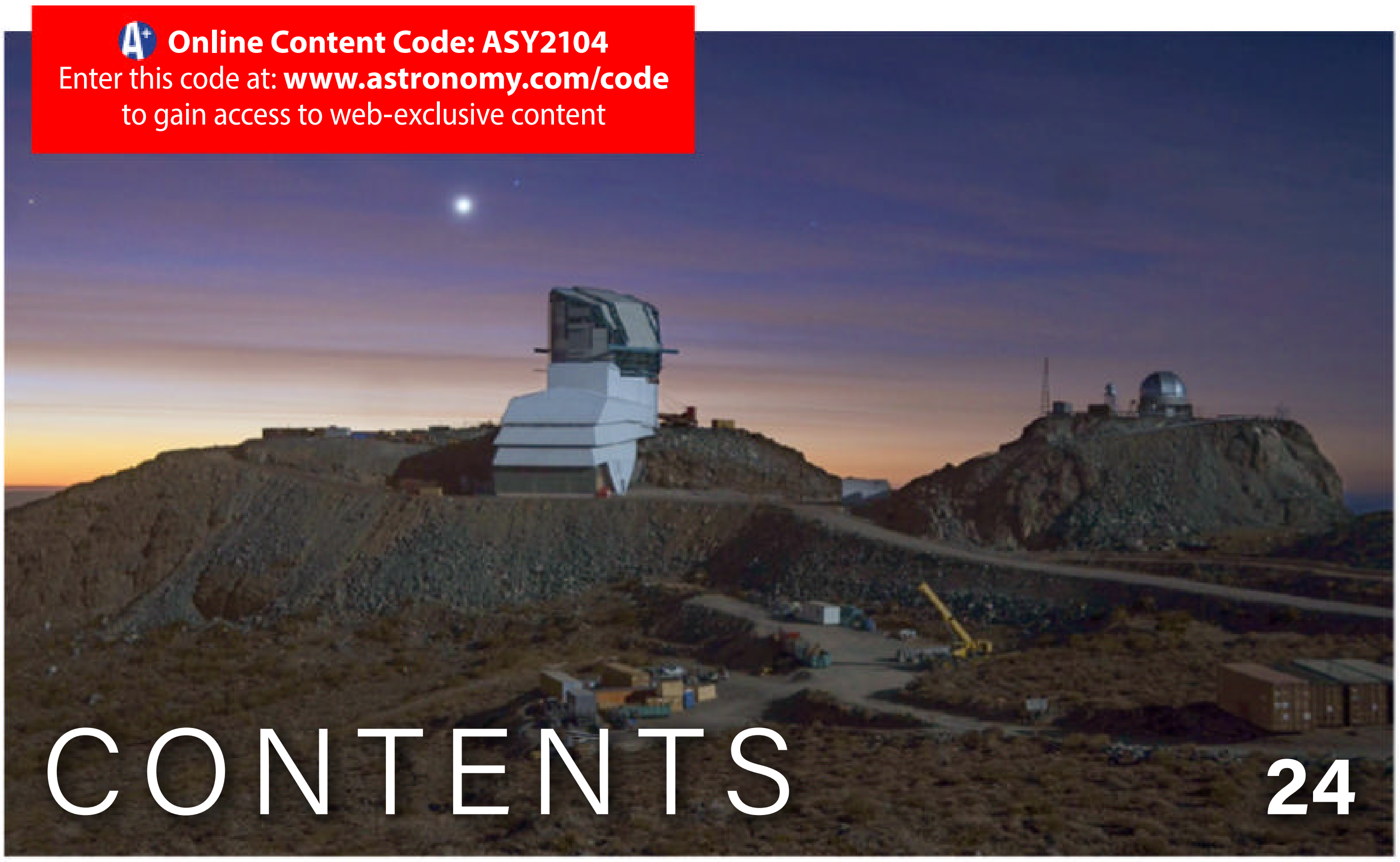

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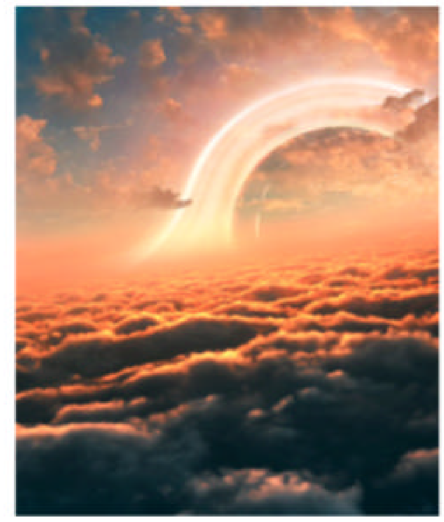

ON THE COVER

A black hole in the distance shields a rogue planet wandering on its own through a distant galaxy.

MARK A. GARLICK/MARKGARLICK.COM

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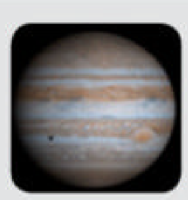

Sky This Week
A daily digest of celestial events.

News
The latest updates from the science and the hobby.

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FROM THE EDITOR

The unlikely story told by rogues

In 2017, astronomers discovered the first known interstellar asteroid, 'Oumuamua, certainly one of many that have traversed our solar system.
ESO/M. KORNMESSER

For a long time, astronomers have been fascinated by rogues — planets, asteroids, comets, stars. In 2017, astronomers found a small, strange asteroid called 'Oumuamua traveling through the solar system, its orbit betraying an origin from beyond the solar system. It was simply cruising through our celestial neighborhood, and we would never see it again. In 2019, researchers discovered another such object, 2I/Borisov — this time a comet, which also had an interstellar orbit. Understanding the nature of the galaxy around us, it's not surprising that there should be many such visitors, in the past and again in the future.

Wandering astronomical bodies require the attention of astronomers. Rogue black holes or vast numbers of planets flying solo through the galaxy have sometimes been suggested as solutions for identifying the dark matter we know exists. Stars like our Sun are born in open clusters that get scattered by tidal forces as they orbit the galactic center, and we know that sometimes individual stars gain velocity and are flung far out into space, escaping their galactic disks.

Science writer Russell Hyman gives us an updated tale of rogues and misfits and what they tell us about the cosmos, beginning on page 16. He examines the murky detective story of uncovering the classifications of such mysterious objects and attempting to trace their origins back over time.

The understanding of such objects is getting a big boost from new telescopes and surveys that are producing mountains of astronomical data. Our other big science story in this issue, a look forward at the Rubin Observatory and Roman Space Telescope also penned by Hyman (page 24), tells us how these instruments will unveil a new era.

The Roman Telescope will hunt primarily for exoplanets, dark energy, and dark matter. But it will also uncover rogue planets floating freely in the galaxy, and could help solve the puzzle of exactly how these misfits fit in.

Yours truly,

David J. Eicher
Editor

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The four largest moons of Jupiter: Io, Europa, Ganymede, and Callisto. NASA/JPL/DLR

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Universal achievement

Your recent January edition titled "The beginning and end of the universe" was the best issue you have ever published. Additionally, of the various science magazines to which I subscribe, your recent edition far surpasses anything any of the others have ever sent my way. *Magnificent* is the only adjective that comes close to doing it justice. Many thanks to all of those who participated. **—John Vaillancourt,** Toronto, ON

Looking at Jupiter's moons

Klaus Brasch and Leo Aerts, in their very nice article about Jupiter's moons, mention that though the moons were discovered by Galileo, their names came from his contemporary, Simon Marius.

Marius independently discovered the moons of Jupiter, but one day after Galileo! Galileo published *Sidereus Nuncius* to include the moons of Jupiter, but Marius didn't publish his results until 1614, in his *Mundus Iovialis Anno MDCIX Detectus Ope Perspicillum* (*World of Jupiter in the Year 1609 Detected With a Perspiculum*).

Also, Marius was using the Julian calendar, so his date of first noting the moons came out in 1609, but that translated to one day after Galileo's notes in January 1610 on the new Gregorian calendar that Galileo, in Italy, was using. The discrepancy played a role in Galileo savaging Marius, ruining his reputation for centuries. **—Jay Pasachoff,** Williamstown, MA

Correction

Several of our readers pointed out a mistake in the "Solar energy" illustration on page 45 of our November issue, in "Gold from the stars." That illustration incorrectly shows the first step of the proton-proton cycle that powers fusion in the Sun as a neutron and proton combining to create deuterium plus a positron and a neutrino. The correct first step of the cycle is *two protons* combining to create those by-products.

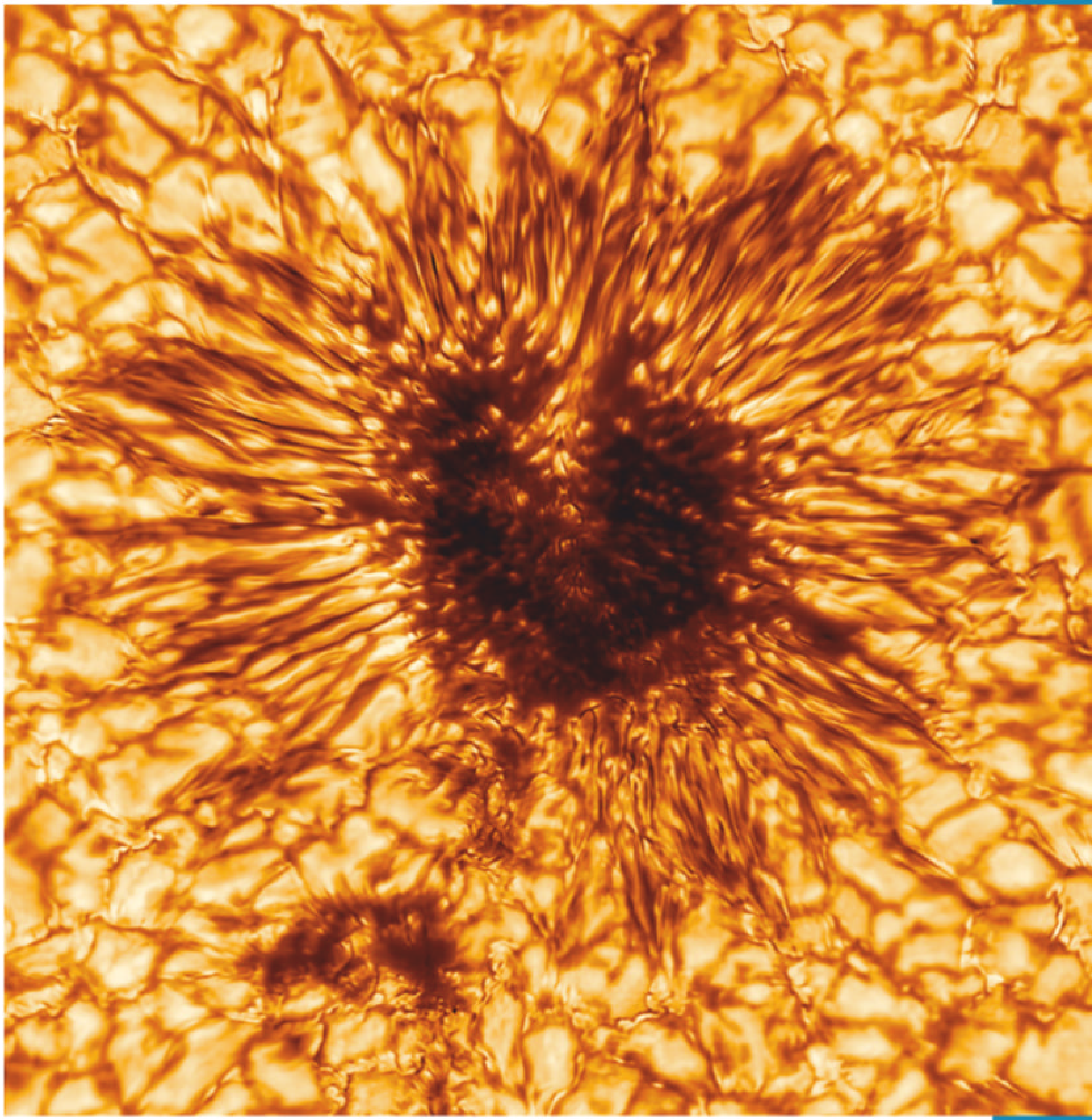
SNAPSHOT

SUNSPOT SNAPSHOT

The Inouye Solar Telescope has released its first image of a sunspot.

Since it began operating in late 2019, the U.S. National Science Foundation's Daniel K. Inouye Solar Telescope — the world's largest solar observatory — has been wowing the world with close-up views of our star. Now, the telescope has released its first image of a sunspot. Such spots, which appear on the surface of the Sun where magnetic field lines converge, look dark because they are cooler than their surroundings. But *cool* is a relative term, as the center of this sunspot is still hotter than 7,500 degrees Fahrenheit (4,150 degrees Celsius).

Measuring roughly 10,000 miles (16,100 kilometers) across, the sunspot is large enough to encompass the entire Earth. The close-up reveals structures as small as 12 miles (20 km) in size and shows the spot with a resolution 2.5 times greater than any previous image. This photo was snapped in January 2020, shortly after the Sun reached solar minimum. But now that the Sun's activity is ramping up again, researchers are eager to observe more sunspots with this new level of detail to learn more about the processes that shape our star's activity. —ALISON KLESMAN



NSO/AURA/NSF; X-RAY: NASA/CXC/UNIV OF MICHIGAN/K. GÜLTEKIN; OPTICAL: NASA/STSCI AND NAOJ/SUBARU; INFRARED: NSF/NOAO/KPNO. BOTTOM FROM LEFT: WASHINGTON STATE UNIVERSITY; IMAGE PROCESSING: TRAVIS RECTOR (UNIVERSITY OF ALASKA ANCHORAGE)/MAHDI ZAMANI/DAVIDE DE MARTIN; CTIO/NOIRLAB/NSF/AURA/SMASH/D. NIDEVER (MONTANA STATE UNIVERSITY)

HOT BYTES

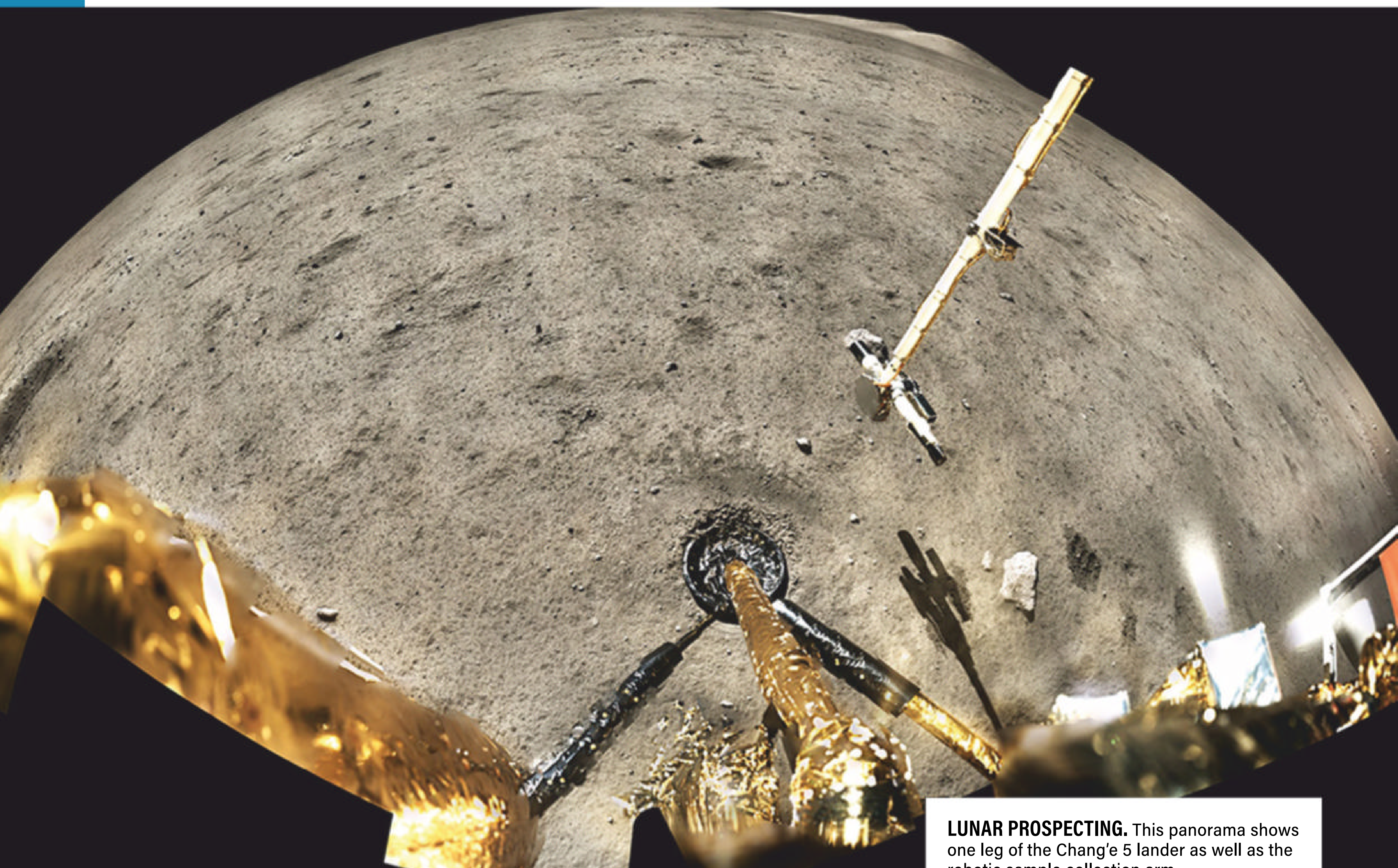
ROCKET ORIGAMI
Borrowing techniques from the Japanese art of paper-folding, researchers at Washington State University have created a prototype plastic bladder that won't crack while pumping liquid fuel at ultracold temperatures.

BENT OUT OF SHAPE
New research suggests the disk of our galaxy was violently warped by the Large Magellanic Cloud (LMC) some 700 million years ago. The LMC is still influencing the Milky Way, pulling our galaxy in the direction of the constellation Pegasus.

BYE-BYE BLACK HOLE
The Hubble and Chandra space telescopes failed to find a supermassive black hole expected to lurk in the central galaxy of the cluster Abell 2261, suggesting a galactic merger ejected the black hole.

CHINA'S LUNAR LOOT RETURNED

The ambitious Chang'e 5 mission retrieved several pounds of material from the Moon.



LUNAR PROSPECTING. This panorama shows one leg of the Chang'e 5 lander as well as the robotic sample collection arm. CNSA

» December 16 was a momentous day for the China National Space Administration (CNSA): The long-awaited Chang'e 5 mission safely returned to Earth, carrying with it about 3.8 pounds (1.7 kilograms) of lunar material plucked from the Moon. The mission marks the first time in almost 45 years that lunar samples have been brought to Earth.

It was also CNSA's most complex mission yet. The spacecraft itself consisted of four primary components: a service module, a lander, an ascent module, and an Earth return module. China's heavy-lifting Long March 5 rocket carried the craft to space on November 23. To reach the Moon, Chang'e 5 then performed several burn maneuvers, followed by braking burns that allowed it to enter orbit some 125 miles (200 kilometers) above the lunar surface. After dropping to an altitude of about 9.5 miles (15 km), the lander and ascent module detached from the rest of the craft to make a self-guided landing. According to CNSA officials, the craft touched down at 10:11 A.M. EST on December 1 near a mountain called Mons Rümker in the Ocean of Storms.

PICKUP AND DELIVERY

Once on the surface, the lander deployed its solar panels to power its array of instruments, including ground-penetrating radar, spectrometers, and a drill capable of collecting samples as far as 6.5 feet (2 meters) below the lunar surface.

After collection, the samples were transferred to the ascent module, which first used springs to separate from the

A MOLTEN RING GALAXY FORGED

Peering deep into space, the Hubble Space Telescope spotted a distorted galaxy that looks like the subject of a Salvador Dalí painting. The Molten Ring Galaxy, officially named GAL-CLUS-022058s, is a terrific example of an Einstein ring. Directly between us and the Molten Ring sits a galaxy cluster whose gravity amplifies and distorts light from GAL-CLUS-022058s into the view we see here. – HAILEY ROSE MCLAUGHLIN

ESA/HUBBLE & NASA, S. JHA; ACKNOWLEDGMENT: L. SHATZ

lander before firing its own rocket motor. CNSA chose this approach to minimize the risk of damaging both the lander and its precious cargo.

Once in orbit, the ascent module reunited with the service module. After transferring the lunar samples to the enclosed Earth return module, the ascent module was jettisoned and the service module fired its rocket engines to head back home, carrying the Earth return module.

BOUNCE-OFF. The ascent stage of Chang'e 5 lifts off from the lunar surface in this illustration. A set of springs separated the ascent module from the lander module before its engines ignited. CNSA

As the craft approached Earth, the return module detached from the service module and performed a "skip" reentry, where it bounced off the atmosphere once to slow itself before deploying its parachute system and touching down in China's Inner Mongolia region. Helicopter-borne recovery crews using infrared cameras quickly spotted the craft and swooped in to retrieve the samples.

For now, the samples are being prepared for analysis and storage within a special Beijing laboratory. In a CNSA press release, officials said they hope to share some of the returned lunar material with other nations to "promote scientific research, encourage more scientists at home and abroad to participate, and strive to secure more scientific achievements." – DOUG ADLER

QUICK TAKES

CATALYTIC CONVERTER

Researchers have found the first experimental evidence that the Sun fuses some hydrogen by using carbon, nitrogen, and oxygen as catalysts. This "CNO cycle" makes neutrinos as a byproduct, which were detected by the underground Borexino observatory in Italy.

SHIELDS DOWN

Planets rich in uranium and thorium may struggle to host life, according to new research. Heat from these radioactive elements in a planet's mantle may halt the formation of a dynamo-driven magnetic field like Earth's, which shields life from radiation.

MORE LIKE GRAMMA RAYS

In 2017, astronomers spied a brief flash in the most distant known galaxy, GN-z11 — a suspected gamma-ray burst (GRB), a powerful stellar explosion. It would be the oldest known GRB, dating to 420 million years after the Big Bang.

LUNAR COMMONS

The Moon's most valuable sites for science and mining are clustered in just a few regions, warn researchers. Competition among nations and corporations could lead to overcrowding and threaten cultural heritage locations like the Apollo landing sites.

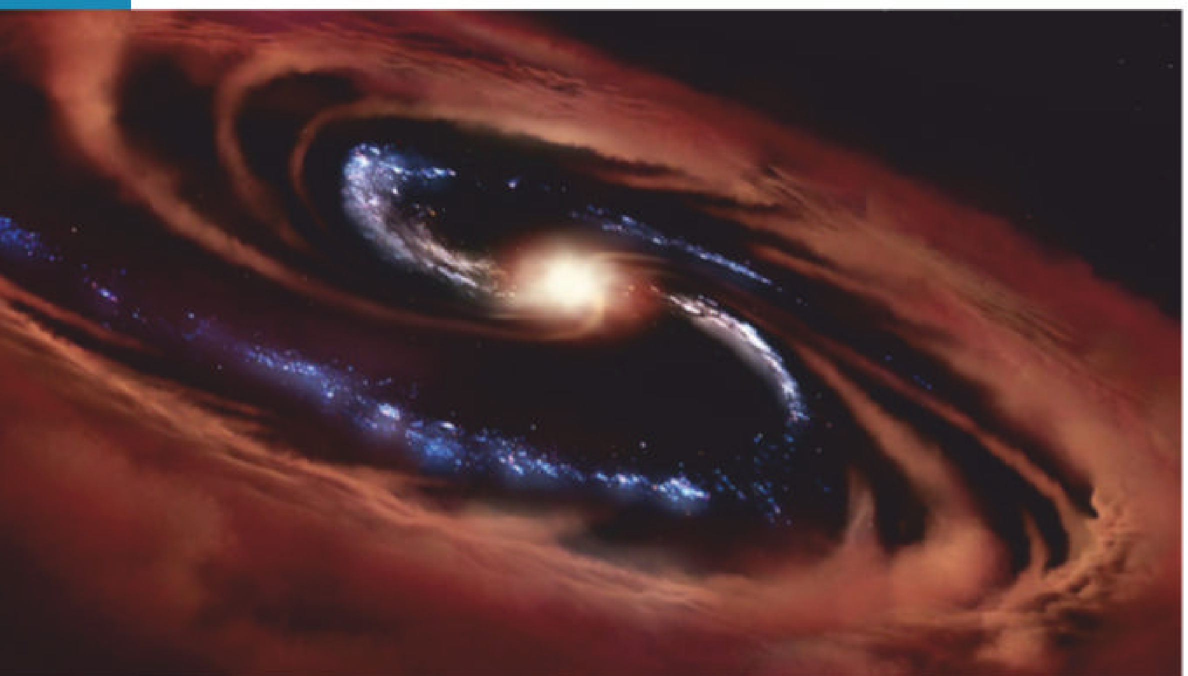
DISTANTLY RELATED

The brown dwarf Oph 98 A has a newfound binary companion — a planet-sized object orbiting five times farther from it than Pluto is from our Sun. The pair's low masses and wide separation mean they share the weakest gravitational bond of any binary system yet found.

SPIDEY SENSE

In zero gravity, spiders use light to stay oriented, suggests a study on the International Space Station. When their habitat lamps were off, the spiders spun unusually symmetric webs. But with lights on, they built their webs towards them, as if aiming for the Sun in the sky. – MARK ZASTROW

Astronomers spot a galaxy in midlife crisis



TRANSITORY PHASE. CQ 4479, shown in this artist's concept, has both an actively growing supermassive black hole (center) and cold gas (orange-brown, outer edges) that is still forming stars. NASA/DANIEL RUTTER

Galaxies, like people, change as they age. Young galaxies are full of gas and dust that fuel intense star formation, while older galaxies are devoid of this material and can't make new suns.

What prompts the change? All massive galaxies host supermassive black holes in their centers. These black holes grow by eating gas and dust, belching out huge amounts of energy in the process. That energy heats the remaining gas throughout the galaxy, preventing it from cooling and clumping together to form more stars — quenching star formation and starting a galaxy down the path of aging.

Now, astronomers using NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) have gotten a glimpse at a unique time in a galaxy's life. The galaxy CQ 4479, which is more than 5.25 billion light-years away, has both an actively feeding black hole and a healthy rate of star formation, making 100 solar masses' worth of stars per year. The discovery was published November 6 in *The Astrophysical Journal*.

CQ 4479 offers a peek into "a very limited time window where you can see both the black hole growing and the stars surrounding it growing at the same time," said Kevin Cooke, a postdoctoral researcher at the University of Kansas (KU) in Lawrence, Kansas, and lead author of the study, in a press release.

"I think this is a galaxy undergoing a midlife crisis," said co-author Allison Kirkpatrick, also at KU. "It's going through one last burst of star formation. … It's forming a few more stars now, and the thing that's ultimately going to kill it is starting to kick in."

The researchers next want to observe CQ 4479 with the Atacama Large Millimeter/submillimeter array, as well as the upcoming James Webb Space Telescope. Studying galaxies transitioning from young and active to old and quiescent will help us better understand galaxy evolution as a whole, as well as improve our picture of how the Milky Way formed and how it will age. —A.K.

2.32×10^{-10} m/s^2

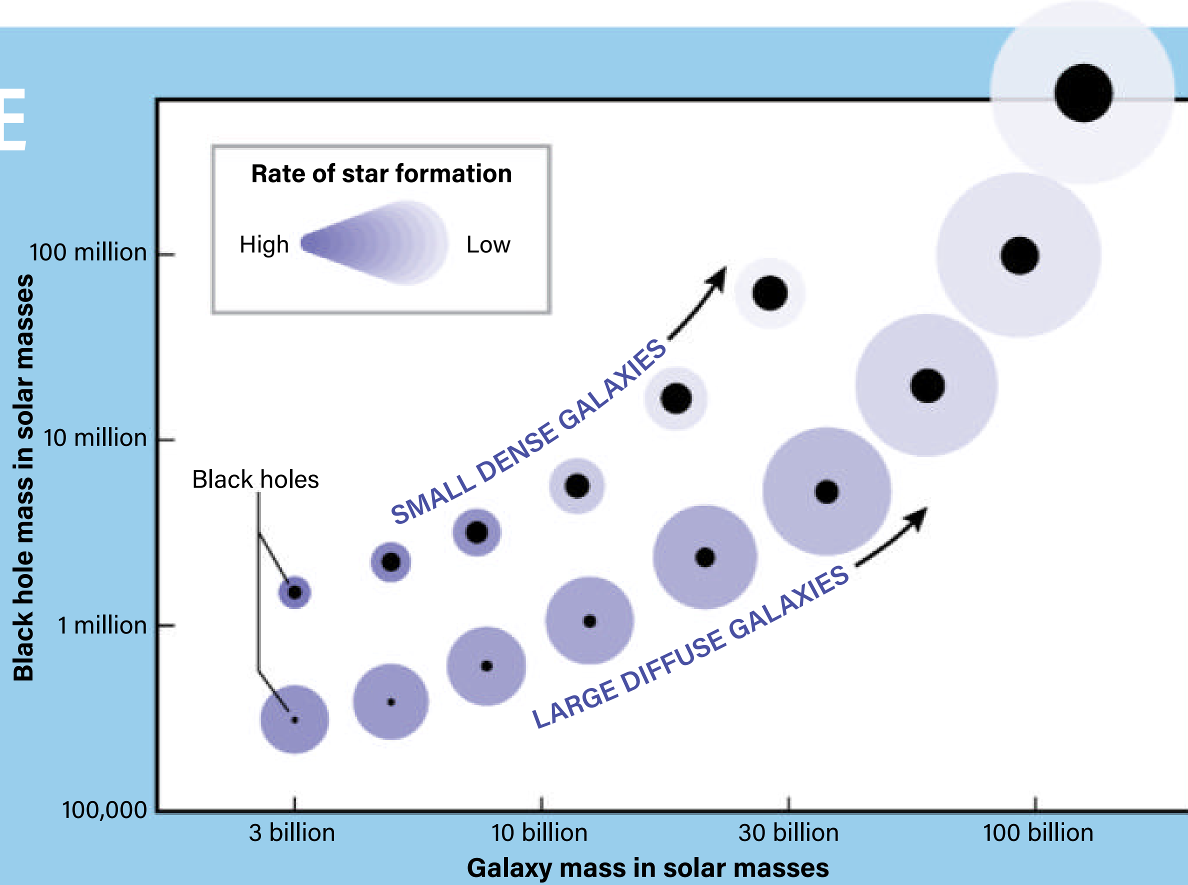
The acceleration of the solar system around the Milky Way, as measured by the Gaia Space Telescope.

NASA, ESA, THE HUBBLE HERITAGE (STSCI/AURA)/HUBBLE-EUROPE (ESA) COLLABORATION, D. PADGETT (GSFC), T. MEGEATH (UNIVERSITY OF TOLEDO), AND B. REIPURTH (UNIVERSITY OF HAWAII)

A HUBBLE CHIAROSCURO MASTERPIECE

Countless artists throughout time have strived to capture the beauty of nature in their work. But Hubble does that with ease. Located some 1,350 light-years from Earth, the stunning Herbig-Haro Jet HH 24 contains a newborn star forming within a giant cloud of cool molecular hydrogen. As the cloud collapses due to gravity, it forms a thick disk of rotating material around the star. And as the star gobbles up this superheated material, some of it escapes as jets that shoot from the star's poles, heating nearby gas to thousands of degrees and lighting up this stunning scene. Eventually, this region will settle down enough for planets to likely be born from the disk of material surrounding the young star. —H.R.M.

HOW SUPERMASSIVE BLACK HOLES KILL THEIR GALAXIES



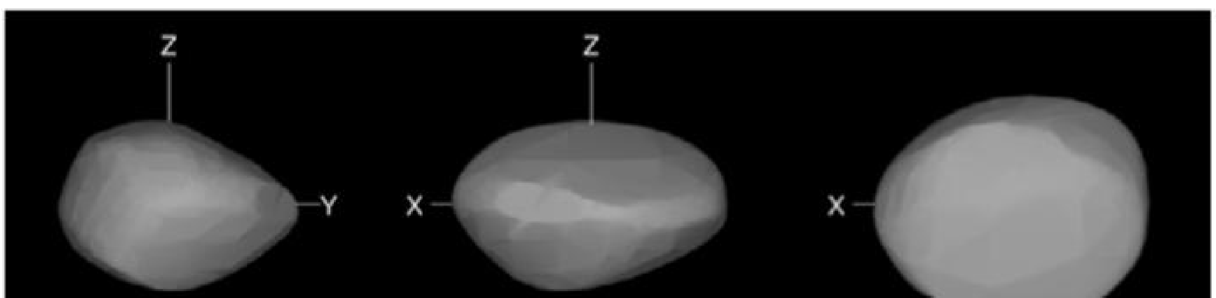
ASTRONOMY: ROEN KELLY, SANDRA FABER/SOFIA QUIROS/SDSS

GALACTIC HEARTWORM. Eventually star formation in galaxies turns off, but astronomers don't understand precisely what causes this quenching. One of the leading ideas is that the galaxy's central black hole acts like a parasite. As the supermassive black hole (SMBH) feeds on nearby material, it disrupts the galaxy's gas supply, cutting off available gas for new stars. New research indicates that quenching depends on the mass of both the central black hole and of the stars in the galaxy combined with the galaxy's radius. Smaller galaxies more densely packed with stars tend to have larger SMBHs, meaning their star formation is cut off a lot sooner than it is for galaxies whose stars are more spread out, as seen in the illustration. Larger, more diffuse galaxies, however, must evolve further before their SMBHs are massive enough to affect their star formation. — CAITLYN BUONGIORNO

FAST FACT

The Milky Way's sister galaxy Andromeda is more quenched than our own and has a supermassive black hole 50 times the mass of the Milky Way's central black hole.

Citizen astronomers map near-Earth asteroid



MODEL POSES. This model of the near-Earth asteroid 1999 AP_{10} was compiled using observations from citizen astronomers.

JOSEF HANUŠ, CHARLES UNIVERSITY & FRANCK MARCHIS, SETI INSTITUTE

Amateur astronomers have always been on the front lines of planetary defense, discovering and tracking near-Earth asteroids (NEAs) that could one day collide with our planet. But now they've taken on a new role: helping to map such an object, revealing its shape.

In a project led by researchers at the SETI Institute, 26 backyard observers from seven countries targeted the 1.2-mile-wide (2 kilometers) asteroid 1999 AP_{10}. All of the observers used an eVscope — a new "smart" telescope model with a built-in CMOS detector produced by the startup Unistellar. (Read our review of the eVscope on page 58 of the March issue.)

Their analysis exploited changes in the asteroid's brightness as it tumbled through space, reflecting sunlight differently at every angle. Through October and November 2020, eVscope users collected 81 sets of observations, which the researchers used (along with some archival data from 2009) to reverse engineer the asteroid's physical shape.

The team presented their results December 9 at the fall meeting of the American Geophysical Union, held online.

Franck Marchis of the SETI Institute tells *Astronomy* that a network of thousands of identical eVscopes is a "game-changer" for pro-am teams. The eVscope calibrates and processes its observations automatically, and results from standardized equipment can be combined more consistently, he notes.

The field of planetary defense suffered a major loss when Arecibo Observatory collapsed in December — it obtained high-resolution data of 20 to 30 NEAs per year. Marchis hopes eVscope campaigns will map one or two NEAs annually, and though that's a small fraction of Arecibo's former output, he says it could help "fill up the gap left by Arecibo." — M.Z.

Far-flung exoplanet resembles long-sought Planet Nine

MIRROR WORLD. HD106906 b occupies an unlikely orbit around its binary host stars 336 light-years away, perhaps providing clues to where the hypothesized Planet Nine may lie in our own neighborhood. ESA/HUBBLE, M. KORNMESSER

An exoplanet circling two stars 336 light-years away may provide clues about where a long-sought world may be hiding in our own solar system.

This strange exoplanet, HD106906 b, was first discovered in 2013 with the Magellan Telescopes at the Las Campanas Observatory in Chile's Atacama Desert. But in order to determine its orbit, astronomers needed the Hubble Space Telescope's clarity and precision. Eleven times the mass of Jupiter, HD106906 b lies more than 730 times the average Earth-Sun separation from its two host stars. At such an incredible distance, it takes the planet 15,000 years to complete one orbit. Not only is HD106906 b remote for an exoplanet, but its orbit is also tilted 30° from the orbital plane of the dusty disc surrounding its host stars.

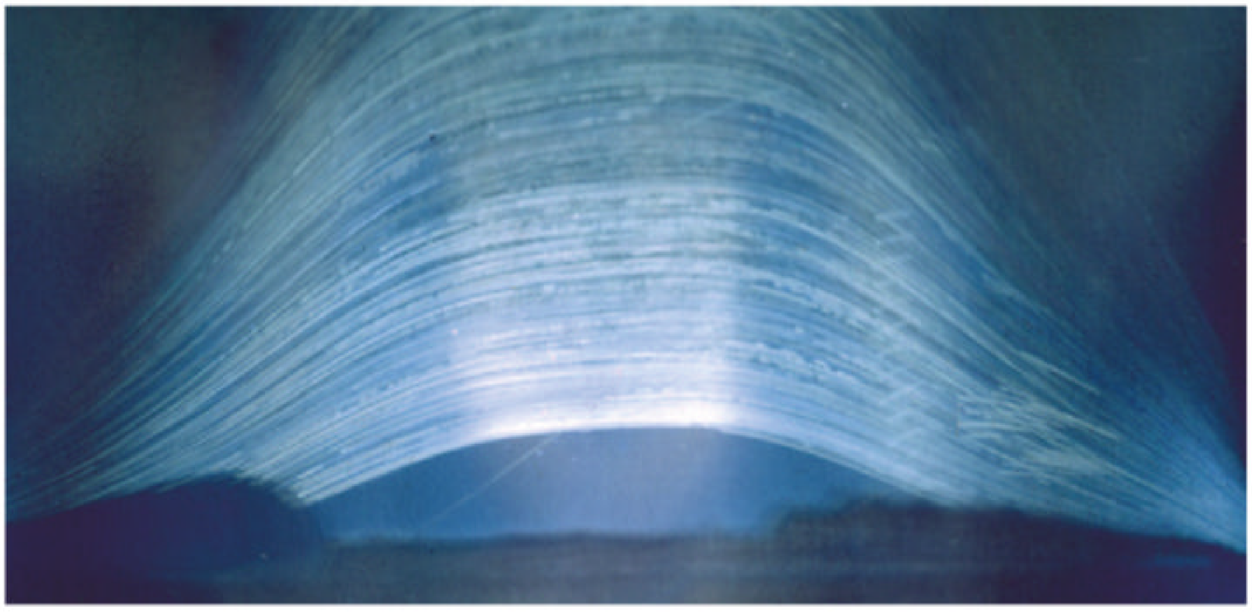
"To highlight why this is weird, we can just look at our own solar system and see that all of the planets lie roughly in the same plane," said study leader Meiji Nguyen in a press release.

It's possible that HD106906 b formed much closer to its twin host stars, but as it traveled through the debris disk surrounding the stars, its orbit decayed. The whirling twin stars then kicked the planet further out into the system when it migrated too close. The planet was almost entirely ejected from the system, but astronomers think a passing star might have stabilized the planet's distant orbit. Candidates for such an interloper have been identified using the European Space Agency's Gaia survey satellite.

Some researchers suspect a similar scenario may have played out in our own solar system, paving the way for the hypothetical Planet Nine. The gravitational influence of such a planet could explain the strange orbits of a unique group of Kuiper Belt objects beyond Neptune.

Planet Nine has yet to be discovered (or even proved to exist). But HD106906 b provides a compelling parallel to the way researchers predict Planet Nine could orbit our Sun. Using the upcoming James Webb Space Telescope, astronomers hope to gather more data on HD106906 b to better understand it, with the goal of finding more planets in similar orbits around other stars. —C.B.

Eight-year Sun trail imaged with beer can

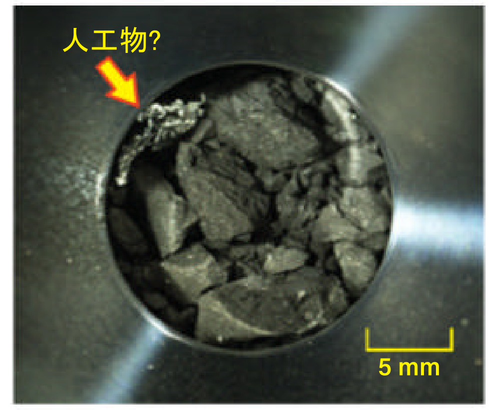


REGINA VALKENBORGH/UNIVERSITY OF HERTFORDSHIRE

In what may be the longest-exposure photograph ever taken, this image captures the path of the Sun over 2,953 days — more than eight years — at the University of Hertfordshire's Bayfordbury Observatory in the U.K. But a high-tech detector didn't take this record-setting image — it was a humble beer can lined with photographic paper, acting as a low-tech pinhole camera. Regina Valkenborgh, a master of fine arts student, placed the beer can on the side of a telescope dome in 2012 — where it sat, forgotten, for eight years, until an observatory staff member removed it in September 2020. The resulting image of the Sun's trail arcing across the sky is a solargraph, recording when the Sun was visible and when it was obscured by cloudy weather. —M.Z.

JAXA

Hayabusa2 delivers asteroid samples to Earth



JAXA

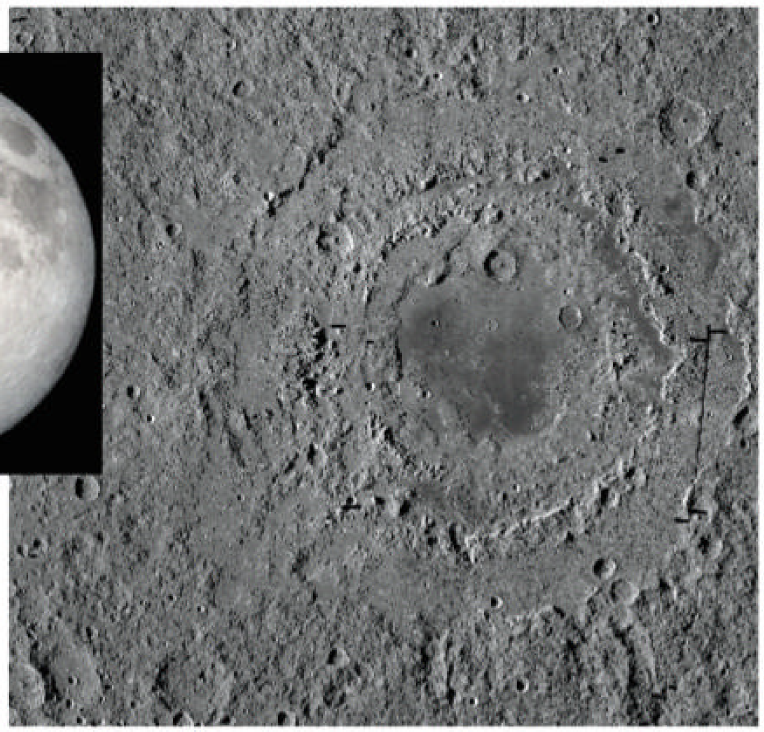
Early on the morning of December 6, Japan's Hayabusa2 safely delivered its payload — precious samples taken from the surface of the asteroid 162173 Ryugu — to the Australian outback. Hayabusa2 launched in 2014 and collected samples from Ryugu in 2019. As it completed its return journey with an Earth flyby on December 5, 2020, the spacecraft released a capsule that left a glowing trail as it reentered the atmosphere, which photographer Coober Pedy captured from South Australia. Once in the lab, the team found a total of 0.2 ounce (5.4 grams) of material — far more than the 0.004 ounce (0.1 g) they had targeted. The capsule also contained a piece of metal, marked 人工物 ("artificial object") in the image. The team hasn't confirmed its origin, but they think it could be a piece of aluminum that broke off of the sampler horn when the projectile used to dislodge samples was fired into the asteroid. –M.Z.

PLANETARY DECADAL

SURVEY SAYS ... Once a decade, planetary scientists take part in a survey run by the U.S. National Research Council to determine the community's research priorities. The findings of this decadal survey help Congress, NASA, and other agencies decide which subjects and potential missions to fund over the next 10 years. In 2020, researchers submitted over 500 white papers, making the case for different topics and mission concepts. Here are the words that have come up most often in their titles, with more common words shown larger. (Note: Related words have been grouped, like *Mars/martian* and *lunar/the Moon*.) –M.Z.

East meets west?

Celestial directions bring on an added layer of confusion.



Mare Orientale, the Eastern Sea, is located on the left side of the Moon, as viewed from Earth. Following a 1961 ruling by the IAU, this is the Moon's western edge. NASA'S SCIENTIFIC VISUALIZATION STUDIO; NASA/GSFC/ARIZONA STATE UNIV./LUNAR RECONNAISSANCE ORBITER

In New York City, it's prestigious to say that you live on the East Side. Conversely, when the film *West Side Story* came out, everyone knew that title referred to rough neighborhoods with street gangs. Directions matter, at least here on Earth.

When we explore the universe, the east-west distinction ranges from critical to irrelevant. A huge, near-light-speed jet races out of the west side of the galaxy M87, but few observers know or care that it's heading toward Leo.

These directions can also get strangely confusing. When Venus is a morning star, it can only be seen in the east. Yet at such times, Venus is listed as having a western elongation. Same with Mercury. On March 6, that charbroiled world reaches its greatest western elongation of 27°, its best of the year. But if you look west, you won't see it. You must instead face east just before dawn.

Now is the best time to be pondering this, since the equinox highlights these cardinal directions. On Saturday, March 20, the Sun rises precisely due east and sets exactly in the west. Those directions have their singular origin in our planet's spin. But for the Sun to rise at the *exact* eastern cardinal spot on the horizon, our world cannot be tilted toward or away from our star, which rarely happens. Instead, it must stand perfectly sideways to the Sun. This occurs only at the equinox.

So, orientation matters. As an interesting aside — to be *oriented* means you correctly know which way you're facing. The word shares some meaning with the outdated term *Orient*, meaning — for those in Europe — the East. Thus, originally, if you knew which way east was, you were oriented.

Originally, if you knew which way east was, you were oriented.

As on Earth, orientation matters in astronomy as well. Directions from binary stars to their dimmer companions routinely allude to the east or west. And here, we've all occasionally been thrown for a loop since our mirrors, lenses, and star diagonals flip or reverse the images. Many observers have discovered that a quick way to get reoriented is to turn off the drive motor. When the object starts drifting, it is reliably toward the west.

And this would be good enough, except the Celestial Police — the International Astronomical Union (IAU) — issued an astonishing decree in 1961. Until then, when the Moon hovered on the meridian at its highest point each night, you knew its right side was its western side, since that limb faced your western horizon. Indeed, as Earth rotated, the Moon's leading edge across the sky was its right, or western, limb.

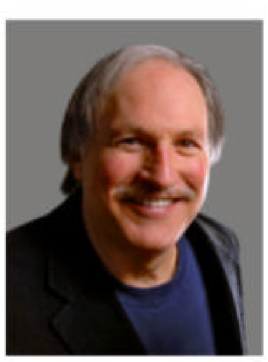
The trailing limb, the one closest to your eastern horizon, was, of course, its eastern side. So, when the German astronomer Julius Franz discovered a major new lunar mare in 1906 right smack on its leftmost edge, he named it Mare Orientale — the Eastern Sea. This dramatic feature comprises a concentric set of circular ridges, like a bull's-eye target. It became more widely known after British popularizer Patrick Moore claimed in a bewildering entry in the 1976 edition of his book *Guide to the Moon* that *he* had discovered and named it. (Thirty years later, Moore conceded Franz's priority.) What's relevant is that both authors affirmed the mare's eastern locale.

But with President John F. Kennedy's promise that the U.S. would soon send astronauts to the Moon, a strange directional issue surfaced. On terrestrial maps, west is always to the left. If people would now explore the Moon, find new features, and make new charts, shouldn't those maps match earthly ones?

"Done!" proclaimed the IAU in 1961. Overnight, the right side of the lunar limb was officially designated its eastern limb, even though it was on the Moon's west side. Which brings us back to Mare Orientale, that eastern sea. Yep, you guessed it — they kept the name, even though it was now located smack on the Moon's newly minted western edge. And this month around the equinox, as the terminator sweeps over the waxing Moon, although it nightly progresses eastward as measured by any compass, GPS, or the sky's universal directions, it's *officially* moving *west* along the Moon's face.

When Rudyard Kipling said of east and west that "never the twain shall meet," he had no idea what was coming a mere quarter-century after his death.

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**



BY BOB BERMAN
Bob's newest book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

Mind-altering Mars

Seeing canals may not be so crazy after all.

ABOVE: In 1877, Italian astronomer Giovanni Schiaparelli first described the network of dark lines on Mars we now call canals. Amateur astronomers can still see and image them today, as shown in this shot (lower right) by Sal LaRiccia of Somerville, Massachusetts, taken October 14, 2020. MAP: WIKIMEDIA COMMONS; IMAGE: SAL LARICCIA

UPPER RIGHT: Schiaparelli added notes to one of his Mars maps (left). A sketch by the author (right) shows the same region of Mars on October 22, 2020. MAP: WIKIMEDIA COMMONS; SKETCH: STEPHEN JAMES O'MEARA

BY STEPHEN JAMES O'MEARA

Stephen is a globe-trotting observer who is always looking for the next great celestial event.

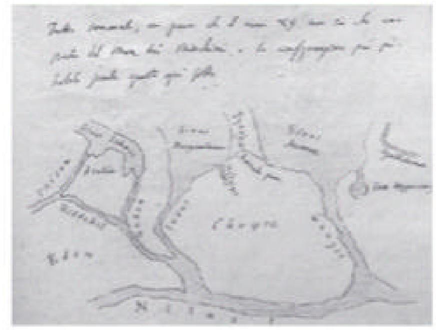
Now that the best apparition of Mars in recent memory has passed, I'd like to share some thoughts on the illusions of its canals. When it comes to canal sightings, many observers mentally brush them away like cobwebs. But to those interested in the history of astronomy and how the eye/mind system works, the study of martian canals is like witnessing how a magician alters visual processing with optical illusions.

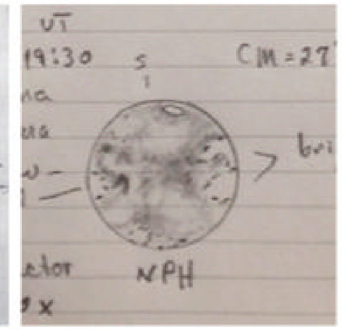
As William Sheehan writes in the August 2015 issue of *The Antiquarian Astronomer*, "The canals still exist — and will always exist — in the subjective realm of illusion, making their appearances when Mars is viewed under the right conditions."

In 2020, I dedicated much observing time to seeking out martian canals — a difficult task, as they were surprisingly rare and fleeting. They don't appear all over the planet at once, as some maps of Mars suggest, but singly and in flashes so quick that the brain doesn't register them with a single sighting. As Percival Lowell wrote in his 1906 book *Mars and Its Canals*: "For so short and sudden are its apparitions that the locating of it is dubiously hard. It is gone each time before he has got its bearings. … Such is the experience every observer of them has had."

During moments of excellent seeing, I saw the features clearly defined.

In my studies, the features I would consider "canals" materialized only when the planet appeared largest (more than 20" in diameter). For the observations, I used a 3-inch refractor at magnifications ranging from 300x to 400x — those typically used by Lowell, and Giovanni Schiaparelli before him.





Irradiation illusion

The Schiaparellian canal Indus was extremely prominent this past apparition. In images, Indus appears as a broad lane of irregularly dark terrain that includes Oxia Palus. During moments of excellent seeing, I saw the features clearly defined — but only when looking directly at them. When my attention strayed, the surrounding bright deserts created an irradiation illusion that narrowed Indus into a thin, beaded linear canal.

The same illusion transformed a dimmer lane of dark terrain in Chryse into the Schiaparellian canal Hydaspes. These canals correspond to real albedo features. As Eugene Antoniadi wrote in his 1930 book *The Planet Mars*, "Schiaparelli's 'canals' have a basis in reality, though they do not exist on Mars as true canals."

Future seeing

According to neurobiologist Mark Changizi, author of *The Vision Revolution*, "We see illusions because our brains are attempting to see the future." And motion, he says, is crucial to the story of illusions. When the brain attempts to generate a perception, Changizi says, it does so by trying to fast-forward a tenth of a second. As a result of this neural delay, we might not perceive an image as it is, but as we expect it might soon be.

And so it appeared on a night of exceptional seeing when I glimpsed the Schiaparellian canals Chrysarrhoas and Sirenius. Unlike with Indus, I could not associate their positions with a linear albedo feature, ruling out the irradiation effect. Both canals began at the tips of pointed mare features. The tips served as arrows that prompted the eye to extend them in the direction they were pointing. The canals always appeared in the mind's eye to drop down (to the north) from these tips, like dripping paint.

In these latter cases, most likely, my brain was gathering data quickly but not accurately. This left an impression of what my mind thought I should see, rather than what was really there. As Lowell himself said in *Mars and Its Canals*, "Of a sudden be made aware of a vision as of a thread stretched somewhere from the blue-green across the orange areas of the disk. Gone as quickly as it came, he will instinctively doubt his own eyesight, and credit to illusion what can so unaccountably disappear."

I'm interested in reading about other experiences. Send your observations to sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara**

The galaxy's marvelous ROGUES and MISFITS

From ploonets to blanets to interstellar interlopers, these nomads defy expectations.

BY RANDALL HYMAN

The gravitationally lensed accretion disk of a supermassive black hole lies on the horizon of a blanet, in this artist's concept.
MARK A. GARLICK/MARKGARLICK.COM

A Jupiter-like planet traverses our galaxy on a lonely journey, having been torn from the gravitational embrace of its host star. Astronomers now think rogue planets may outnumber the stars in the Milky Way. NASA/JPL-CALTECH

Astronomers have been on a rule-breaking, paradigm-shifting, label-blurring whirlwind of research in recent years, focusing on a most unlikely collection of objects: the cosmic homeless.

It began in 1996, when the Hubble Space Telescope detected stars where they shouldn't be, roving free of the gravitational confines of galaxies. Two years later, astronomers spotted the first suspected rogue planet — a world drifting through space without a star to orbit.

Since then, astronomers have uncovered a dozen more potential rogue planets, a pair of interstellar objects, and hundreds of rogue stars that are streaking from our galaxy toward Andromeda.

These mavericks have upended astronomers' traditional practice of classifying a celestial body by the system it calls home — a moon belongs to its planet, a planet belongs to its star, a star to its galaxy, and so on. Astronomers are now thinking well beyond these hierarchical categories, envisioning a cosmos full of moons without planets, planets without stars, and stars or black holes without galaxies. Fortunately, a new generation of space and ground-based observatories is poised to unravel their mysteries.

INTERSTELLAR VISITORS

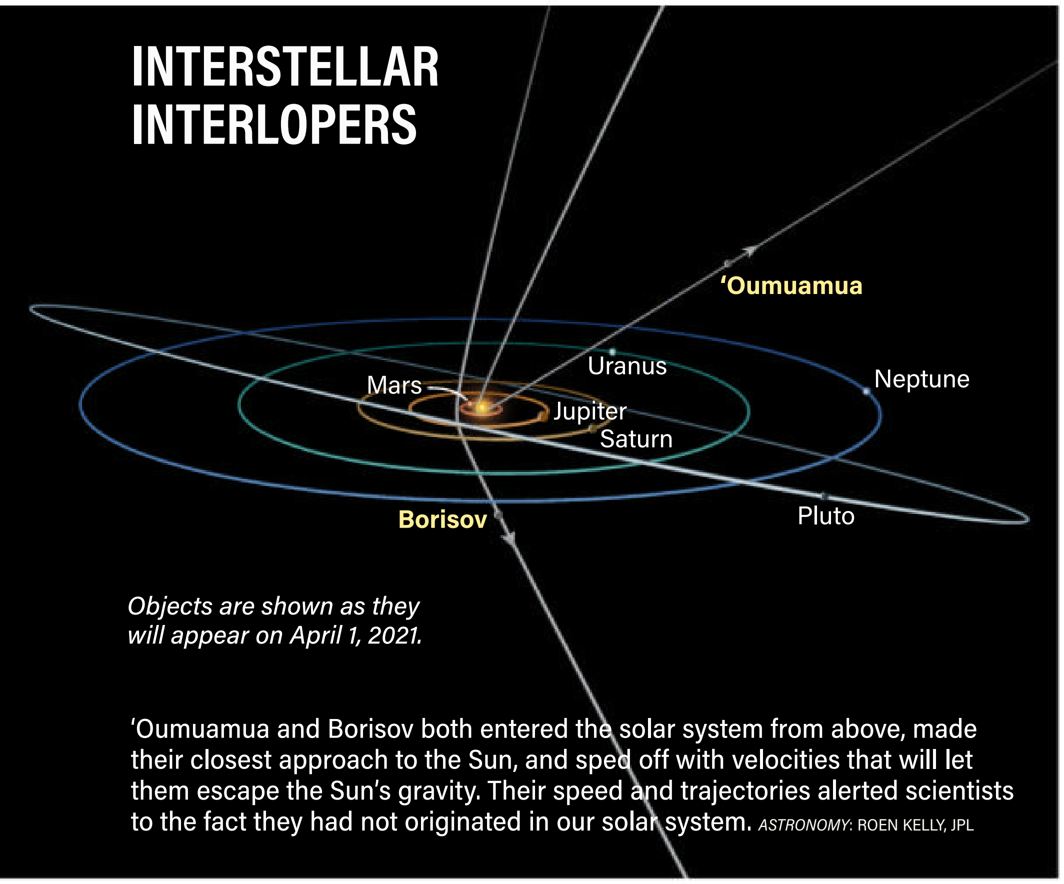
Two of the most recent discoveries have been made in our own backyard. First came 1I/2017 U1 ('Oumuamua), detected in October 2017 by the Pan-STARRS telescope in Hawaii. Next was 2I/Borisov, first seen by its namesake Crimean amateur astronomer in August 2019. Both were unprecedented, the first known visitors from beyond our solar system.

Outwardly, Borisov seemed relatively familiar, with a size and behavior similar to comets native to our solar system. But one big difference was its speed and trajectory — it was moving at 20 miles (32 kilometers) per second and tracing a hyperbolic path. This combination of attributes meant it was foreign: It was moving too fast to be gravitationally bound to the Sun, and the open-ended ellipse (similar to 'Oumuamua's) meant it did not originate here and would ultimately exit the solar system.

'Oumuamua, on the other hand, was unique in every way. It was shaped like a cigar, six times as long as it was wide. It was also moving much slower than Borisov — though still fast enough to escape the solar system after its relatively brief encounter. Every four hours, it brightened and dimmed by a factor of 12, suggesting it was tumbling through space, reflecting glints of sunlight like a coin tossed across the galaxy.

The lack of a cometary coma implied it was a rocky asteroid, but as it sped away from the Sun, something mysterious happened: It accelerated. Astronomers concluded this was most likely due to cometary outgassing — the jetting of frozen

This artist's concept shows the outgassing of interstellar comet 2I/Borisov. NRAO/AUI/NSF, S. DAGNELLO



'Oumuamua and Borisov both entered the solar system from above, made their closest approach to the Sun, and sped off with velocities that will let them escape the Sun's gravity. Their speed and trajectories alerted scientists to the fact they had not originated in our solar system. *ASTRONOMY*: ROEN KELLY, JPL

Researchers think the odd behavior of 'Oumuamua (1I/2017 U1) can be explained if it is venting material into space, as depicted in this artist's concept. ESA/HUBBLE, NASA, ESO, M. KORNMESSER

'OUMUAMUA'S ORIGINS

In their June 2020 paper, Darryl Seligman and his colleagues argued that 'Oumuamua could have been born in the uber-freezers of the cosmos: molecular clouds. Hovering a few degrees above absolute zero at minus 454 degrees Fahrenheit (minus 270 degrees Celsius), with just enough ambient pressure to prevent sudden evaporation of ice, molecular clouds are rich with hydrogen and cold enough to freeze and clump it around large dust particles.

But detractors of this idea say 'Oumuamua would have taken hundreds of millions of years to travel from the nearest giant molecular cloud — far too long for a chunk of hydrogen ice to survive gradual sublimation, which causes ice to transition directly from a solid to a gas.

Instead, for the hydrogen ice scenario to be correct, 'Oumuamua must be a remarkably young object born nearby. Last year, a study out of the University of Western Ontario by Tim Hallatt and Paul Wiegert argued that 'Oumuamua could have formed less than 100 million years ago, right where the young stars presently surrounding us were about to coalesce. Their analysis rests on 'Oumuamua's slow velocity relative to the stellar neighborhood we are now passing through as we orbit the galaxy's center — in other words, they argued that *we* intercepted *'Oumuamua*, not the other way around. *—R.H.*

gas released by solar heating. But if this were true, the gas should have both created a visible halo of gas and dust, known as a coma, and increased 'Oumuamua's tumble rate. Neither occurred.

ALIEN ICEBERG

So, was 'Oumuamua a comet, an asteroid, or something else? Because it was not spotted until it was well outbound, 40 days after whipping around the Sun, astronomers lacked vital information about its behavior.

Some proposed that 'Oumuamua could be an alien spaceship or solar sail. Most astronomers discounted both of these theories since no radio signals were detected and 'Oumuamua's football-field length would have required a paper-thin sail in order to generate its observed acceleration.

Other researchers suggested a more natural explanation: It was venting gas along successive points of one side as they rotated into direct sunlight. This would cause it to rock back and forth like a pendulum, its surface alternately heated and cooled in searing sunlight and frigid shadow.

Most recently, some of the same authors published a paper in *The Astrophysical Journal Letters* last June, proposing that 'Oumuamua is a hydrogen iceberg. Interstellar molecular hydrogen ice (H_2) has long been theorized to exist, but never detected. It is a substance so mysterious that some cosmologists once believed molecular clouds might harbor vast quantities of it as the source of dark matter — the stuff that holds our galaxy together.

"It sounds farfetched because we've never seen hydrogen ice, but if you assume it's correct, it explains every weird thing about 'Oumuamua," says Darryl Seligman, a postdoctoral fellow at the University of Chicago and a co-author of the study.

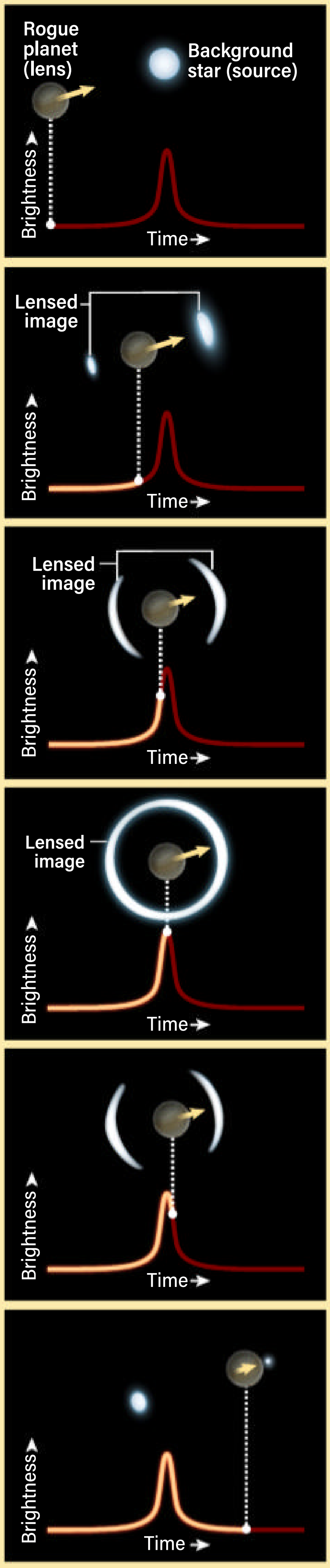
By Seligman's reckoning, other candidates for outgassing would have been easily detectable or required a large amount of material to be ejected. Hydrogen ice explains 'Oumuamua's odd behavior because it is both difficult to detect and serves as a supercharged fuel.

"Molecular hydrogen is by far the best accelerant," says Seligman. "For nitrogen [and others] to work, you would need the surface to be almost completely covered, whereas for hydrogen you could have a gunky thing with some frozen hydrogen and other stuff in there, which is a lot easier to form."

It could also explain 'Oumuamua's long, shard-like shape. According to Seligman's reconstruction, when our Sun began pelting it with photons, the surface along the object's long axis was more exposed and melted quicker. "It's exactly what happens to a bar of soap in the shower," he says. "What you get is this little withered-away fragment that's very elongated and very small."

We will never see 'Oumuamua again and will never know exactly what it was. But the serendipity of spotting 'Oumuamua and Borisov in the span of just two years hints that we are missing many of their siblings. Luckily, the technology

ROGUES REVEALED



Rogue planets give off very little light, but they can be detected when they move in front of a background star and bend the passing light with their gravity, focusing it like a lens. Initially, a second image of the star appears on the other side of the invisible rogue, like a mirage. When the planet moves directly in front of the background star, it acts like a magnifying glass, forming a ringlike image and making the star appear much brighter. *ASTRONOMY*: ROEN KELLY, AFTER JAN SKOWRON/ASTRONOMICAL OBSERVATORY, UNIVERSITY OF WARSAW

needed to spot them will soon be available. Sitting atop a mountain in Chile, the Vera C. Rubin Observatory is aiming to be fully operational in 2023. Its powerful telescope is designed to scan the entire sky every three nights with a 3,200-megapixel camera (the world's largest) and will be capable of spotting objects in the solar system like interstellar interlopers and near-Earth asteroids, as well as more distant events like supernovae and gamma-ray bursts.

PLANETS GONE ROGUE

Later this decade, NASA's planned Nancy Grace Roman Space Telescope will begin to search for another kind of nomad: rogue planets, or worlds without stars. Roman will match Hubble's resolution, yet cover 100 times its field of view and see deeper into infrared to cut through galactic dust and gas.

The telescope will primarily hunt for exoplanets, dark energy, and dark matter. But according to a recent study led by researchers at Ohio State, Roman is likely to reveal something equally startling: a galaxy filled with more rogue planets than visible stars.

"I don't think people really have a concept of what rogue planets are, let alone that the galaxy might be teeming with them," says Ohio State professor and study co-author Scott Gaudi. "The detection of 'Oumuamua demonstrates that extremely low-mass free-floating objects have likely been drifting in and out of our solar system the whole time we've been doing astronomy, and it's just now that we have the technology to detect them," he says.

One of the most exciting things about Roman is it can detect rogue planets as light as Pluto, says Gaudi. The technique it will use is called gravitational microlensing, which has already been used by ground-based observatories to identify a handful of likely rogue planets. Gravitational microlensing takes advantage of a phenomenon Einstein predicted over a century ago: The gravitational field of a large mass bends and magnifies light that originates behind it. In this case, when a planet passes in front of a more distant star, the star's amplified brightness alerts astronomers to a lensing event. The duration of the event reveals the mass of the planet, or so-called lens.

"The less massive the lens, the shorter the microlensing event," says Przemek Mróz, a postdoctoral fellow at Caltech. Mróz is also a member of the University of Warsaw-led Optical Gravitational Lensing Experiment (OGLE), which uses a 1.3-meter telescope in Chile to look for such occurrences. "Most of the observed events, which typically last several days, are caused by stars," he adds. "Microlensing events attributed to free-floating planets have timescales of barely a few hours."

In a study published this past November, Mróz and his colleagues reported finding a rogue candidate smaller than Earth with a record-breaking microlensing event of just 41.5 minutes. The OGLE team estimates a planet's mass not just by the duration of the event, but also by the shape of the observed light curve, which shows how the background star's brightness changes over time. Combining future observations with Roman and the Earth-based Rubin Observatory will allow

The 1.3-meter telescope used by the Optical Gravitational Lensing Experiment monitors the brightness of nearly 2 billion stars. In addition to rogue planets, it has also uncovered over 2,400 Cepheid variable stars, mapped in yellow on this image of the sky above the observatory. K. ULACZYK/J. SKOWRON/OGLE/ASTRONOMICAL OBSERVATORY, UNIVERSITY OF WARSAW

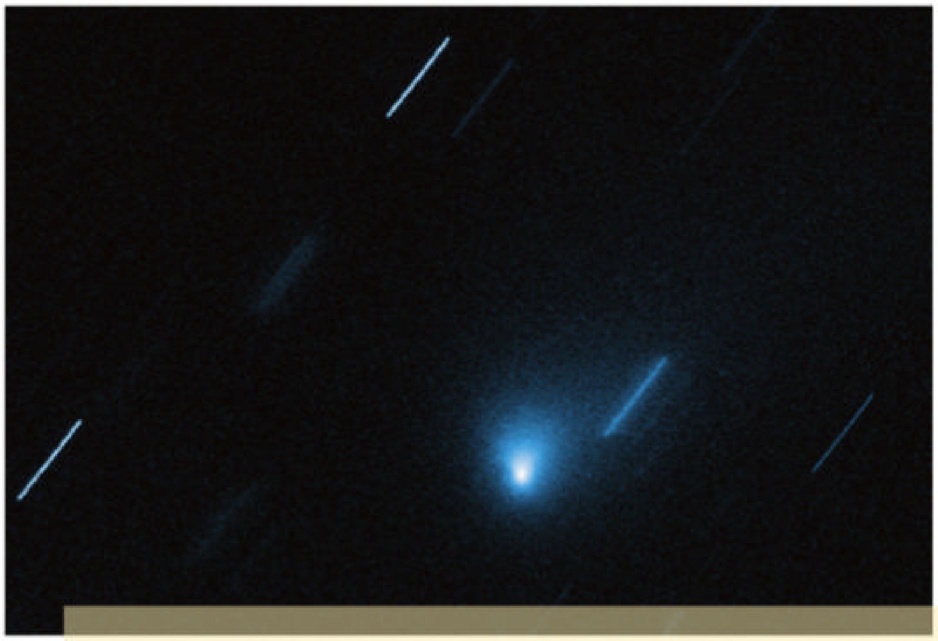
scientists to triangulate distances and obtain even more accurate mass estimates. The team believes that this particular exoplanet is either free-floating or at least eight times as far away from its star as Earth is from the Sun.

Astronomers have attempted to explain rogue planets in several ways. One scenario is that rogue planets are orphans marooned by their home stars as they morphed into red giants. As the stars puffed away their outer layers, they lost both mass and their gravitational grip on their most distant worlds. (Neptune and Uranus may share this fate when our own star enters its final stages of life.) An alternative scenario suggests that a passing star can rip planets with wide orbits away from their home star's distant embrace, leaving them adrift. A third explanation is that rogues are cast out in their youth, overpowered by more massive siblings and flung into the void as they compete to accrete material around their parent star.

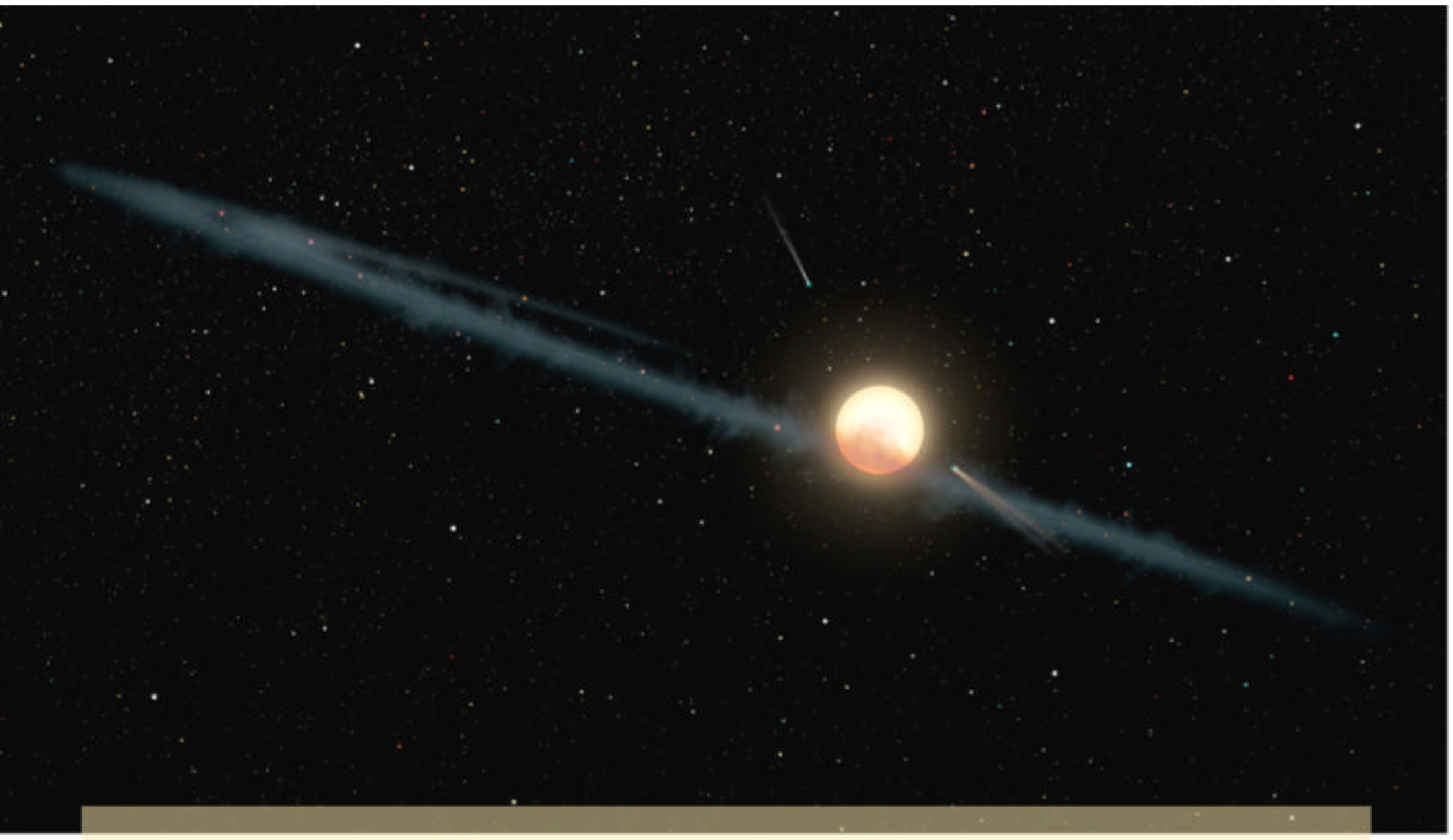
Some objects that appear to be rogue planets may actually be expired brown dwarfs — failed stars that have spent all their deuterium fuel and cannot generate enough pressure and heat to kickstart any other nuclear reactions. Such brown dwarfs, which must initially weigh at least 13 Jupiters to burn deuterium, would cool and shrink as they lost the radiative pressure needed to support their mass.

The coldest brown dwarf on record is around minus 10 degrees Fahrenheit (minus 23 degrees Celsius), notes Melodie Kao of Arizona State University, "and that's cooler than the surface of Earth. So is it really a planet, or is it a brown dwarf? That is a big point of debate among astronomers."

And despite a mounting list of rogue planet candidates, it is not yet possible to verify which are true nomads and which are in deceivingly wide orbits around a distant host star. That may have to wait until the next generation of giant 30-meter telescopes comes online several years from now. Their resolving power will be able to swiftly distinguish a host star — if



Comet 2I/Borisov sped through the solar system so quickly that the Hubble Space Telescope's attempts to track it during exposures resulted in the background star trails seen here. Borisov's cometlike coma is also clearly visible. NASA, ESA, AND J. DEPASQUALE (STSCI)



Rings of debris are the most likely explanation for the mysterious dimming of Tabby's Star, as seen in this artist's concept. The rings could be the remnants of ploonets — moons that escaped their host planets. NASA/JPL-CALTECH

there is one — from a background star as their motions through the galaxy separate them on the sky.

WAYWARD MOONS

If planets can go rogue, what about their moons? The search has already begun for orphaned exomoons within stellar systems — which one team of researchers has dubbed ploonets. Since astronomers think exomoons are more numerous than exoplanets, the existence of ploonets seems likely. But detecting them will stretch the capabilities even of next-generation current technology.

So far, nearly everything we have learned about ploonets comes from models. According to recent simulations, ploonets are born from chaotic tangos between their parent planet and the host star. The team in Chile that coined the term was focused on hot Jupiters, giant exoplanets that have spiraled inward to Mercury-like distances from their stars. As such a planet gets closer to its host star, it experiences tidal forces that distort it. Due to a complex interplay of gravity and friction, the tidal bulge slows the planet's rotation while giving a boost to the moon's momentum, sending the latter into a higher orbit. As distance grows, the gravitational bond between planet and moon can become so weak that the host star tears the moon away as a distinct planet.

A 2019 study identified another way moons might go rogue — when a giant planet and its moons orbit a star that is part of binary system. The gravity of the second star nudges the planet into a disrupted, eccentric orbit that sends it whipping so close by its host star that the planet loses "custody," and the star adopts the moon into an independent circumstellar orbit — assuming it doesn't swallow and vaporize it first.

The study found that only 10 percent of ploonets outlive their parent planets. The rest plummet into their star, smash into their parents, or are vaporized by stellar radiation, leaving an orbiting ring of dust, gas, and debris. Such debris rings can also repeatedly dim their host star, which could explain the erratic — and mysterious — dimming of Tabby's Star in the constellation Cygnus. Moons that fail to achieve runaway status and are destroyed by their parent planet also may explain the peculiar case of an exoplanet roughly 430 light-years away, which appears to have no fewer than 37 rings around it.

"All these scenarios almost definitely happen," says Miguel Martinez of Northwestern University, lead author of the 2019 study. "The question is whether the rates are large enough that we can detect these events with current data and instruments. The fact that we've seen one Tabby's Star so far, instead of a lot of them, shouldn't be surprising."

For now, such leftover debris fields may be the best chance for astronomers to infer the existence of ploonets. After all, even if astronomers detect a runaway ploonet orbiting its host star, it would be hard to distinguish it from normal planets. "I don't think anyone has seriously looked at that problem yet," says Martinez. Perhaps astronomers will find ploonets and not even realize they have found them.

STARS UNLEASHED

If moons can be dislodged from planets and planets can be torn from stars, can stars be flung from galaxies? A century ago, even the question would have been nonsensical, for our galaxy was thought to encompass the entire universe. The very concept of multiple galaxies

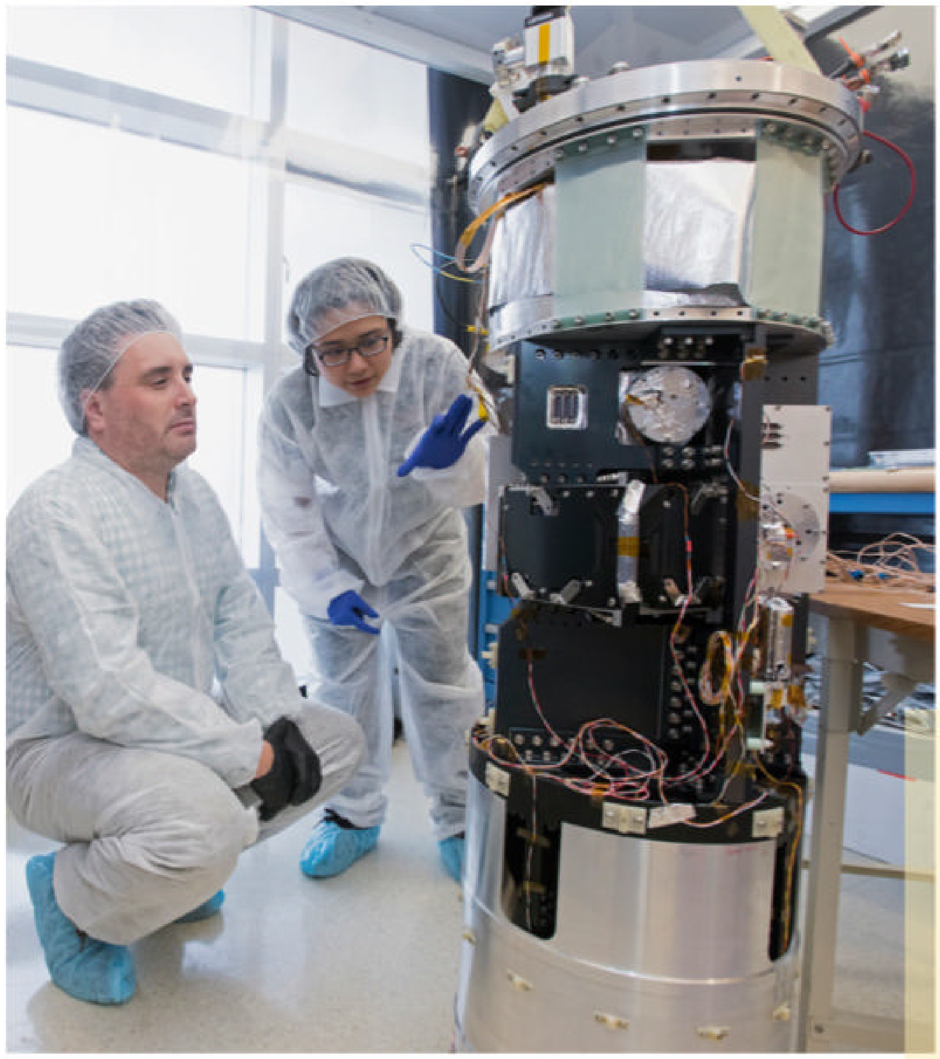
NASA's Nancy Grace Roman Space Telescope — seen here in an artist's concept — is scheduled to launch later this decade. NASA'S GODDARD SPACE FLIGHT CENTER

was mocked by the world's top astronomers.

But Henrietta Leavitt's discovery in 1908 that the pulse of variable Cepheid stars could be used to mark distances — plus Edwin Hubble's measurements of Cepheids in the Andromeda Galaxy in 1924 — proved that the universe comprises countless galaxies, each containing billions of stars held together by extraordinary gravitational glue.

That made it hard to imagine that stars could breach and escape such rigid boundaries. Then, in 1997, Hubble imaged hundreds of red giant stars hovering amid the Virgo galaxy cluster, far removed from any particular galaxy. Subsequent measurements in 2005 by scientists at the Harvard-Smithsonian Center for Astrophysics clocked stars flung from our galaxy at nearly 1.5 million mph (2.4 million km/h). Several years ago, a team led by Vanderbilt astronomers discovered hundreds more such hypervelocity stars — which they called rogue stars — on the outskirts of the Milky Way, heading for the Andromeda Galaxy.

Around that same time, Michael Zemcov, an assistant professor at Rochester Institute of Technology, started using sounding rockets carrying near-infrared telescopes to peer into the darkest patches of the sky, hoping to detect light from primordial galaxies. His team succeeded in detecting a faint, diffuse glow — but it was far too blue and bright to come from such distant sources, whose light has been heavily redshifted, or stretched out to redder wavelengths. They concluded the glow came from rogue stars — more rogue stars than anyone had ever imagined existing in the universe.



ABOVE: The CIBER-2 mission will be launched on a Black Brant sounding rocket similar to this one, seen launching from NASA's Wallops Flight Facility in Virginia. NASA

LEFT: Michael Zemcov and Chi Nguyen of the Rochester Institute of Technology examine the CIBER-2 payload in February 2019. A. SUE WEISLER/RIT

Zemcov thinks these stars are ejected when galaxies crash into each other. These collisions are "sloppy," he explains. "[The galaxies] merge and get bigger, but you lose some of the batter out of the bowl."

He believes extremely distant rogue stars may help solve a problem of missing matter: According to cosmologists, a significant amount of mass and light that should be visible is missing from the universe, even after adding up all known galaxies. (This "missing baryon problem" is separate from dark matter, the mysterious stuff that permeates the universe and holds galaxies together.) "Our work says that if you sum up all of the light from the galaxies that you see, it would be roughly the same as the amount of light outside of galaxies [from rogue stars]," Zemcov says.

There are more exotic, alternative explanations for this feeble ubiquitous light, such as decaying dark matter, but Zemcov believes his explanation fits best. This spring, his team plans to launch a follow-up rocket, called the Cosmic Infrared Background ExpeRiment-2, or CIBER-2. With additional capability extending into the visible-light spectrum, they think it will be able to prove the mysterious signal is starlight.

INTO THE FOLD

Our gallery of intergalactic rogues doesn't end there. Some scientists suspect that the globular clusters wandering the gaps between galaxies in the Virgo cluster might actually be orbiting homeless black holes flung from galaxies in fatal mismatches with bigger opponents.

And last August, astronomers in Japan took the notion of homelessness to its most extreme. They calculated that, amid the vast maelstrom of gas and debris spinning around supermassive black holes at the centers of galaxies, starless planets 3,000 times the mass of Earth could form. These blanets, as the team called them, would be trapped in 1-million-year orbits 10 light-years from their surrogate "star," the event horizon.

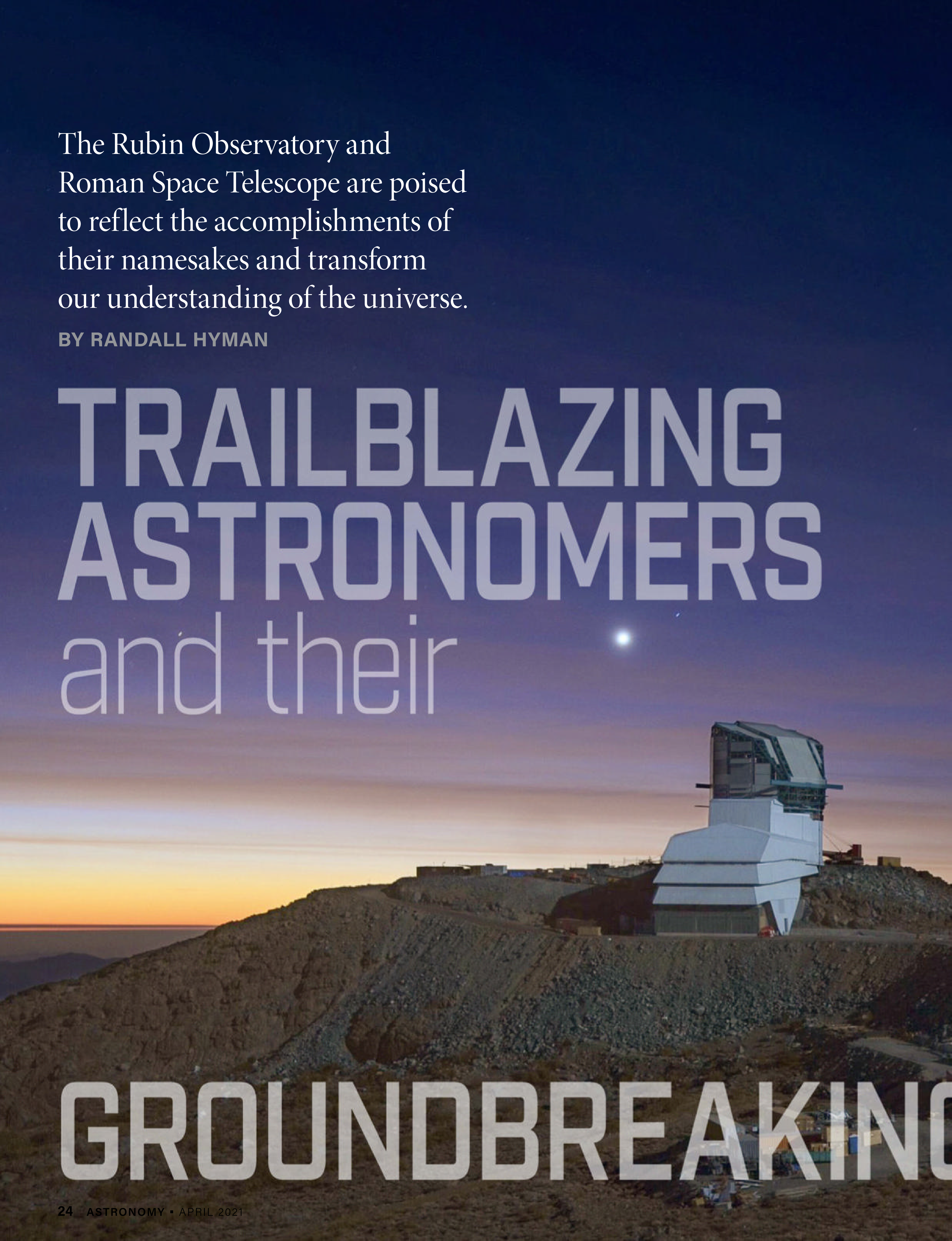
The realm of rogues can be dizzying. Moons become ploonets. Failed stars become planets. Interstellar asteroids behave like comets. Black holes give rise to blanets. And astronomers believe there may be as many planets floating between stars as stars in our galaxy — or stars drifting between galaxies as galaxies in the universe. As telescopes peer ever more keenly into space, the cast of characters promises to grow richer, upending the story of our solar system, our galaxy, and the farthest reaches of the cosmos.

Randall Hyman *writes about science and natural history for various magazines including* Discover, Science, Smithsonian *and* National Wildlife.

The Rubin Observatory and Roman Space Telescope are poised to reflect the accomplishments of their namesakes and transform our understanding of the universe.

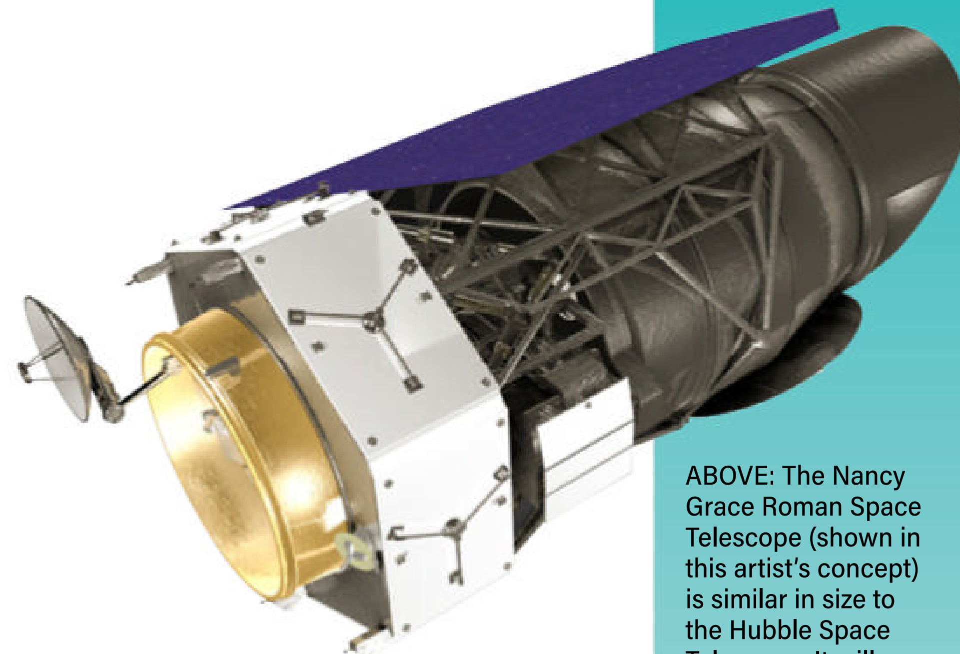
BY RANDALL HYMAN

TRAILBLAZING ASTRONOMERS and their GROUNDBREAKING



This iconic photo shows Vera C. Rubin at work in the Carnegie Institution for Science's Department of Terrestrial Magnetism. AIP EMILIO SEGRÈ VISUAL ARCHIVES, RUBIN COLLECTION

Seen here at NASA's Goddard Space Flight Center in the early 1970s, Nancy Grace Roman was an instrumental figure in astronomical research, as well as the development and launch of numerous space telescopes. NASA



ABOVE: The Nancy Grace Roman Space Telescope (shown in this artist's concept) is similar in size to the Hubble Space Telescope. It will orbit the Sun alongside Earth from one of five gravitationally stable points in the Earth-Sun system. NASA

BELOW: A Full Moon lights the darkening sky over the Vera C. Rubin Observatory on May 5, 2020. RUBIN OBSERVATORY/NSF/AURA

Changing your name is not a decision to be taken lightly. So when two of the most powerful and revolutionary upcoming astronomical observatories were renamed, people took notice.

Say goodbye to the Large Synoptic Survey Telescope and the Wide Field Infrared Survey Telescope, and say hello to the Vera C. Rubin Observatory and the Nancy Grace Roman Space Telescope. Recently rechristened from acronyms — LSST and WFIRST, respectively — to human names, these observatories are expected to become two of the decade's most powerful survey tools. Together they will probe dark matter, dark energy, exoplanets, asteroids, fleeting celestial phenomena, and the evolution of our universe.

But their renaming reflects another revolution in science that is long overdue. Scientists are finally paying tribute to female pioneers of astronomy by naming important observatories after them.

TOP: A triumphant team poses with the 8.4-meter Simonyi Survey Telescope's primary and tertiary mirror blank in 2008. The mirror was cast at the University of Arizona's Steward Observatory Mirror Laboratory in Tucson, Arizona. HOWARD LESTER/LSST CORPORATION

ABOVE: Engineers test the setup of the Rubin Observatory's 3,200-megapixel camera in a clean room at the summit. ANDY FREEBERG/SLAC NATIONAL ACCELERATOR LABORATORY

Both namesake women were towering figures in their respective fields of study. Vera C. Rubin produced compelling evidence of dark matter, ushering in what *The New York Times* called a "Copernican-scale change" in cosmology. Nancy Grace Roman's research led to fundamental insights about our galaxy's structure. As NASA's first chief of astronomy, Roman also became known as the "mother" of the Hubble Space Telescope and was a prime driver behind numerous other space observatories.

Like Rubin and Roman's biographies, both observatories are packed with superlatives. The Rubin Observatory, expected to rev up atop a mountain in Chile late next year and achieve full operation in late 2023, features the world's first 3.2-billion-pixel digital camera. Its 8.4-meter Simonyi Survey Telescope's design is so unique that it garnered $40 million in private funding, principally from Microsoft gurus Charles Simonyi and Bill Gates, long before federal funding kicked in for the rest of the project.

The Roman Space Telescope, for its part, packs the same brilliant sub-arcsecond resolution as Hubble, but covers a field of view 100 times greater and can switch targets much more quickly. Its focus on near-infrared wavelengths allows it to penetrate dust and gas beyond Hubble's vision. Following Earth from afar while sharing its orbit around the Sun, Roman will be up to 1,000 times more efficient than Hubble as a survey telescope.

The massive amount of data produced by both observatories will require specialized algorithms and, for Rubin, dedicated processing centers to handle the deluge of new information. If all goes as planned, the two observatories will play key roles in advancing the field of astronomy — contributions fitting of their namesakes, who did the same in their lifetimes.

Shedding light on dark matter

Dark matter was first postulated in 1933 by Swiss astronomer Fritz Zwicky when he found that the galaxies of the Coma Cluster were moving too fast for the group to stick together based on the visible content of its galaxies. His idea was controversial: Without what he called *dunkle Materie*, or dark matter, only a change in the laws of physics could explain how our universe holds itself together.

Four decades later, Rubin came to the topic while seeking safe harbor from the controversy and "competitive atmosphere," as she called it, of her previous work on the distributions and motions of galaxies. She and instrumentalist Kent Ford — who developed the specialized spectrograph central to her research — published seminal papers on the rotation curves of spiral galaxies. Rubin found that stars orbiting at the outskirts of galaxies were moving inexplicably fast. In other words, the galaxies' rotation curves were flat.

Physics dictates that the farther from a concentration of mass something orbits, the weaker the gravitational force it experiences and the slower it moves. Based on the amount of visible matter in the outskirts of these galaxies, which dropped off with distance, the stars should be orbiting more slowly. But as Rubin looked to a galaxy's fringes, she found that stars kept up their speed, as if under the influence of the gravitational pull of some unseen matter.

Rubin's measurements were compelling evidence that some invisible material — Zwicky's *dunkle Materie* — resided within and around galaxies. Dark matter and the equally mysterious dark energy — the presumed explanation for the universe's accelerating

expansion — are now thought to account for 95 percent of the known universe (25 percent dark matter, 70 percent dark energy).

"We became astronomers thinking we were studying the universe," Rubin later said of the ramifications of her game-changing discovery, "and now we learn that we are just studying the five or 10 percent that is luminous."

The Rubin Observatory

The Rubin Observatory, nearing completion atop Cerro Pachón in Chile, may help astronomers probe the other 95 percent.

The telescope's mammoth digital camera — which, at the size of a small SUV, is the world's largest — weighs several tons and comprises 189 ultra-precise CCD detectors of 16 megapixels each, grouped in clusters of nine. It employs three lenses, the largest of which is 5 feet (1.5 m) in diameter, principally to correct chromatic aberration, and six filters to capture the entire visible spectrum (plus a touch of infrared and ultraviolet light).

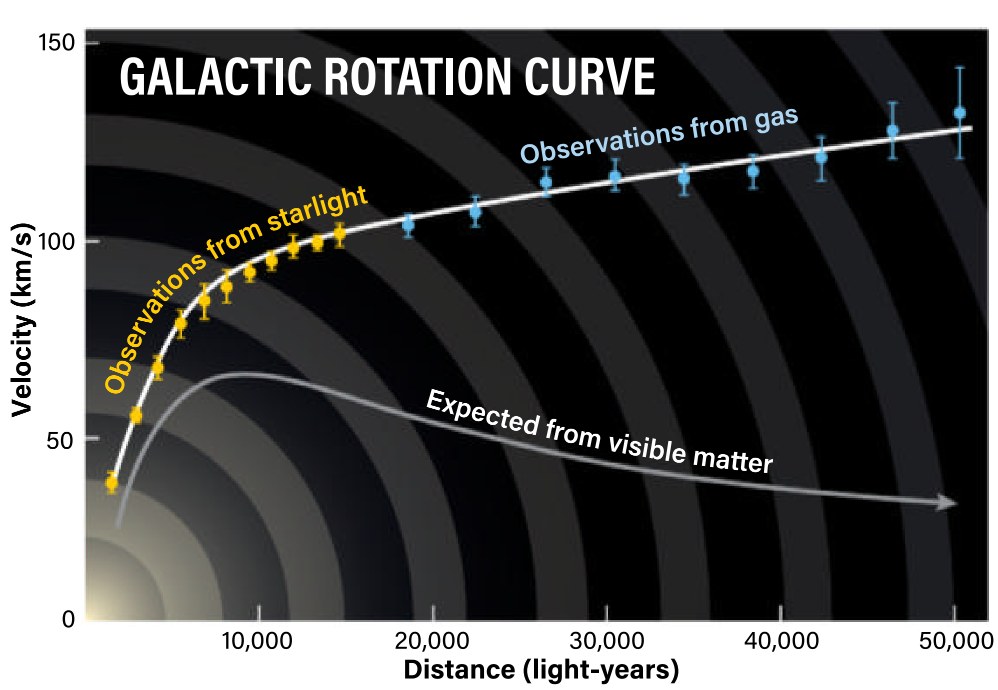
The telescope's mirror also breaks new ground: It features a tertiary embedded within the primary, fabricated as a single casting to maximize internal stability and minimize weight. This integrated mirror system allows the telescope to slew to new sky positions in just five seconds, meaning the observatory can survey the entire Southern Hemisphere sky down to 24th magnitude every three days.

The resulting data flow will be unprecedented for a single astronomical instrument. Each night, it will generate 20 terabytes of data and issue some 10 million alerts of any changes it detects in the sky, mostly asteroids. Every alert will be processed and broadcast worldwide in less than 60 seconds.

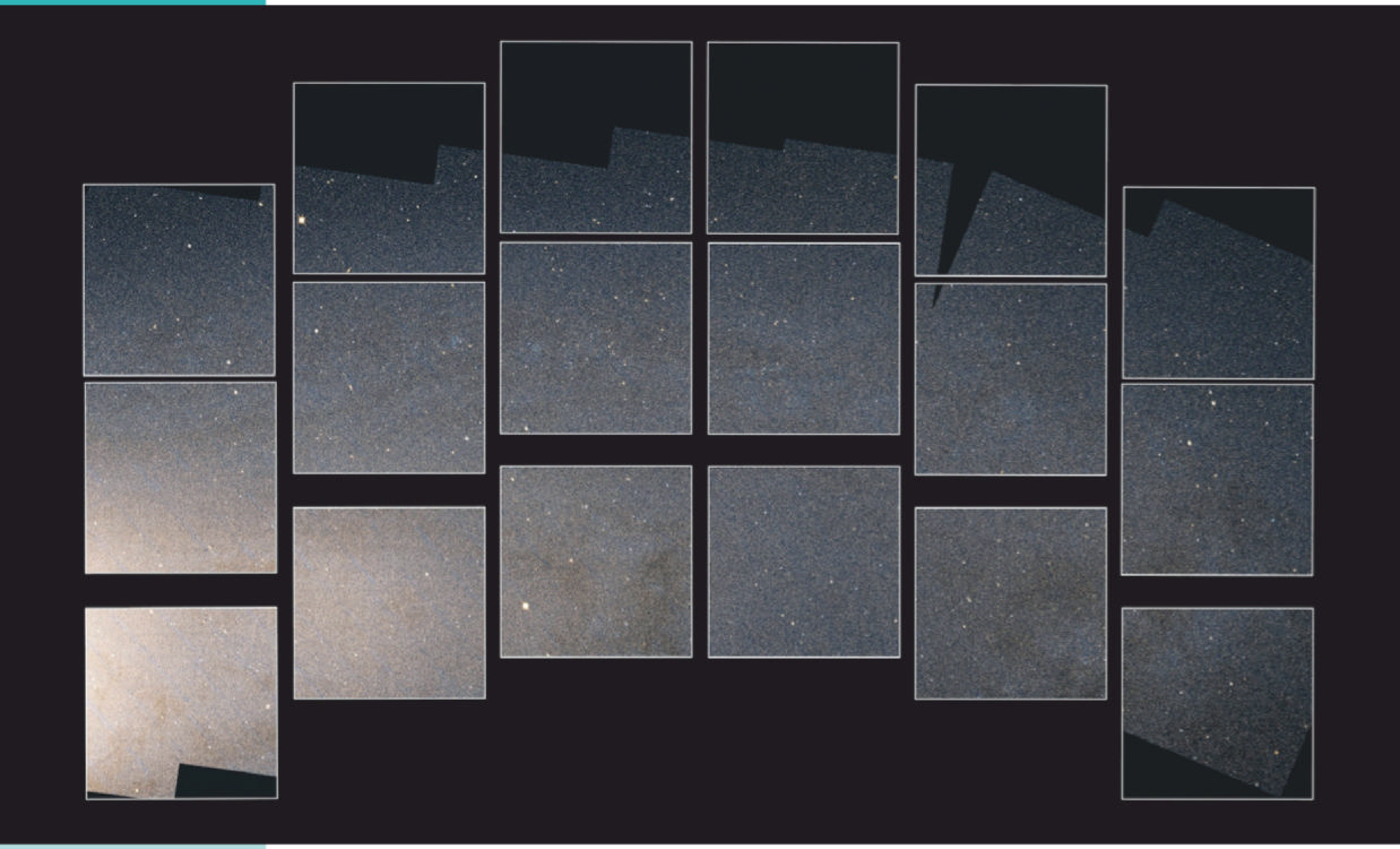
During its 10-year Legacy Survey of Space and Time (which now uses the acronym LSST), Rubin's dedicated computers will catalog some 20 billion galaxies and a similar number of stars, as well as several million new supernovae and about 6 million asteroids. By then, the observatory will have surveyed every part of the southern sky more than 800 times, producing several hundred thousand terabytes of data. In doing so, the Rubin Observatory may open the door to understanding dark matter using a phenomenon called gravitational lensing.

Based on Einstein's theory of general relativity, massive objects act as lenses by bending and amplifying light as it travels near them. By observing how galaxy clusters affect the light from more distant objects behind them, such as galaxies and bright quasars, astronomers can calculate the total mass of the cluster. Comparing this to the mass of the clusters' *visible* matter reveals how much *invisible* dark matter is hiding within them.

Rubin made her groundbreaking discoveries of dark matter using an image tube spectrograph developed by Kent Ford and attached to the No. 1 36-inch telescope at Kitt Peak National Observatory. KPNO/NOIRLAB/NSF/AURA



Rubin's work showed that the outer regions of galaxies are rotating faster than expected based on the mass of the galaxies' visible matter. This figure, which compares the observed rotation rate of stars and gas in M33 (white line) to the expected rotation rate (gray line) means the galaxy has more mass than indicated by its visible matter alone. That extra mass is dark matter. *ASTRONOMY*: ROEN KELLY, AFTER MARIO DE LEO/WIKIMEDIA COMMONS



ABOVE: The Roman Space Telescope's wide field of view will allow it to image vast swaths of the sky in a single shot. This simulated view of the Andromeda Galaxy (M31) shows how much the camera will cover in one image — in this case, a region spanning 34,000 light-years and containing more than 50 million stars. GSFC/SVS

RIGHT: Roman, posing here in 1966 with a model of the observatory that would become the Hubble Space Telescope, became known as the mother of Hubble for her dedication in seeing the project come to fruition. During her time at NASA, Roman was the driving force behind many other space observatories, including the Cosmic Background Explorer satellite. NASA

Shaping NASA astronomy

While Rubin looked at galaxies, Roman focused on the characteristics of stars within the Milky Way. Her seminal 1950 *Astrophysical Journal* paper on stellar ages and star formation redefined the structure of our galaxy.

Because younger stars are born of the expelled nuclear remnants of older stars, they contain more complex elements than their forebears. Astronomers call anything heavier than helium and hydrogen (the two lightest elements, which primarily fuel stars) a metal. Thus, older stars have lower metallicity, or metal content, than younger stars. Analyzing and characterizing starlight, Roman found that older, redder stars have slower, more elliptical, and more highly inclined orbits around the galactic center than younger, bluer, faster-moving stars, which follow circular orbits and hug the galactic plane as they form.

In 1956, this research elicited an invitation to the opening of the Byurakan Observatory in Armenia in the Soviet Union. With only three Americans attending, this brought Roman notice back home. And just a year later, the Russians launched Sputnik. The space race was on and, in 1959, Roman joined the newly formed NASA Office of Space Science.

"The chance to start with a clean slate to map out a program that I thought would influence astronomy for fifty years was more than I could resist," Roman wrote in an autobiography published in *Annual Review of Astronomy and Astrophysics* shortly after her death.

As a NASA administrator, Roman ended her research career but led the way on several orbiting space observatories in the ensuing years. And under her fierce leadership and lobbying, the Hubble Space Telescope survived countless assaults and setbacks, earning her nickname as the mother of Hubble. But in her time at NASA, Roman's endeavors set the stage for many other projects as well, including the Chandra X-ray Observatory and the Spitzer Space Telescope.

The Roman Space Telescope

Planned to launch in the mid-2020s, Roman's namesake space-based telescope will focus on near-infrared wavelengths across both hemispheres of the sky. Its 2.4-meter mirror, similar in size to Hubble's, will have a 300-megapixel camera capable of achieving 0.1-arcsecond resolution across the telescope's massive 0.28-square-degree field of view. Roman will produce 1.3 terabytes of data each day from its roughly elliptical orbit around the second Lagrange point in Earth's orbit — one of five gravitationally stable points in the Earth-Sun system.

The telescope will also carry an innovative coronagraph capable of blocking the overpowering light of distant target stars to spot the dim, otherwise invisible exoplanets around them. This coronagraph will use two medal-sized mirrors, each with 2,000 tiny pistons making constant adjustments to keep their surfaces within specs. Engineers expect the instrument to be 1,000 times more sensitive than existing coronagraphs, able to detect exoplanets between 20 million and 1 billion times fainter than their host star, as long as they appear more than 0.15" apart on the sky. That's akin to detecting a firefly hovering near a lighthouse from 1,000 miles (1,600 kilometers) away.

Facing barriers

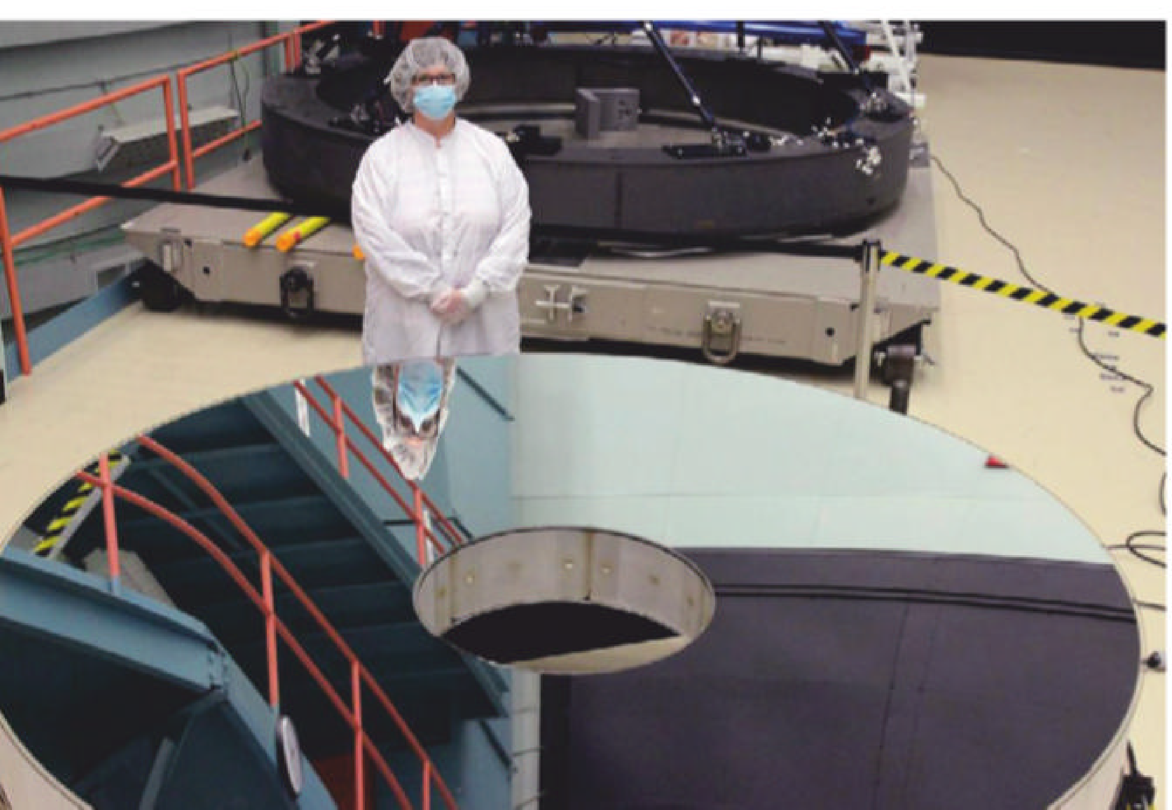
Female scientists have long faced adversity. Like their counterparts in other disciplines, women in astronomy have endured discrimination, gross pay inequities, ridicule, and the indignity of seeing their own research garner accolades for male colleagues. Nonetheless, Rubin and Roman pressed on in a field that was rife with sexism before the term had even been coined. (According to Merriam-Webster, the first known use of *sexism* with its current definition was in 1963.)

Rubin's parents nurtured her early interests in astronomy and music. Her father, an electrical engineer, helped her build her own telescope in her teens. Roman's father, a geophysicist, likewise encouraged his daughter's passion for astronomy and math, while her mother stoked Roman's imagination with nighttime walks to marvel at the northern lights and constellations.

After high school, the realities of male-dominated science began to encroach for both. Born in 1925 (three years before Rubin), Roman applied to college first and was accepted at Swarthmore College. Upon failing to convince Roman not to major in science, the college's dean of women had nothing more to do with her for the next four years, Roman wrote.

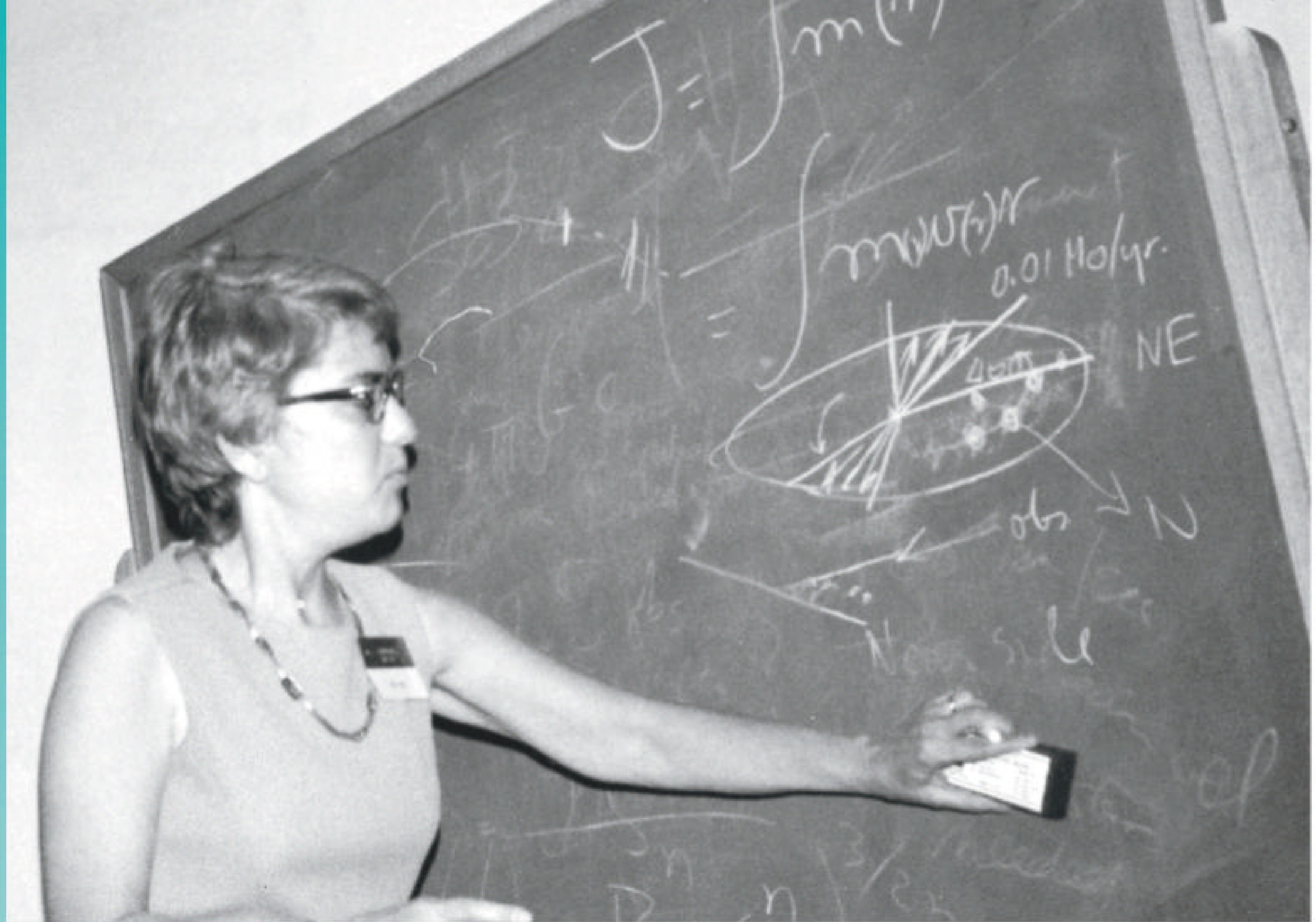
Rubin later applied to study astronomy at the same school, but they declined her application and suggested she find a more ladylike career. She went instead to Vassar College in 1945, where Maria Mitchell, America's first female astronomer, had taught 75 years earlier. Rubin aced her classes and graduated a year early, marrying straight out of school.

She applied to Princeton University next, but they summarily rejected her — it would be decades before they admitted any woman at all. In 1948, Rubin and her husband, Robert, went instead



ABOVE: Formerly the Wide Field Infrared Survey Telescope, or WFIRST, the Nancy Grace Roman Space Telescope's capabilities include a field of view 100 times larger than Hubble's, as well as an advanced coronagraph that will allow it to block starlight and see dim exoplanets circling their suns. GSFC/SVS

LEFT: A technician stands with the Roman Space Telescope's 2.4-meter primary mirror. Despite the similarity in size, Roman's primary weighs less than one-fourth as much as Hubble's, thanks to improvements in materials and technology since the latter was constructed. L3HARRIS TECHNOLOGIES



ABOVE: Rubin uses a blackboard to illustrate a point during the May 1971 Mayall Symposium. AIP EMILIO SEGRÈ VISUAL ARCHIVES, DOROTHY CRAWFORD COLLECTION

LOWER RIGHT: This composite photo and computer rendering shows the final Vera C. Rubin Observatory building, previously known as the Large Synoptic Survey Telescope, or LSST. In December 2020, the observatory unveiled its official logo (upper right). Its colors and design reflect the observatory's physical appearance and scientific mission. RUBIN OBSERVATORY/NSF/AURA; RUBIN OBSERVTORY

to Cornell University, where he worked toward his Ph.D. while she pursued a master's degree.

After two years of study, Rubin's final thesis on the velocity distribution of galaxies was so impressive that her department chair, William Shaw, offered to present it at an upcoming annual astronomy conference. But that offer came with one major condition. Rubin, pregnant with her first child and due shortly before the conference, couldn't possibly go, he said. So, Shaw would present the research under his name, not hers. She declined his "offer" and instead attended herself. The morning after her presentation, *The Washington Post* front page bore the headline "Young Mother Finds Center of Creation."

In 1951, the Rubins left Cornell for Washington, D.C., where Robert took a position at the Johns Hopkins Applied Physics Laboratory (APL). Within a year, it was clear that his wife desperately missed her research, so Robert encouraged her to pursue a Ph.D. at Georgetown University. While pregnant with their second child, Rubin was soon rubbing shoulders with prominent scientists again. After long days at APL, Robert would drive her to Georgetown for evening classes. He would then park outside and wait, eating his supper in their car.

Roman, meanwhile, graduated from Swarthmore in 1946 and went to the University of Chicago to earn a Ph.D. When she first met the professor who would become her thesis advisor, William Morgan, he told her to go to his house to change the bed since his wife was sick. Stunned, she complied. Roman soon discovered that most of the professors considered educating women a waste of time, since they were all destined to marry and become homemakers.

Morgan rarely met with her and went six months without acknowledging the simplest greeting, Roman wrote. He *was* willing, on the other hand, to abscond with her research and present it as his own at a prestigious Vatican conference. On the night before her final oral exam, Morgan agreed to meet, but scheduled their session at midnight. "He decided to use it as an occasion for petting," she wrote. "I moved his hand several times, trying to go on with our conversation."

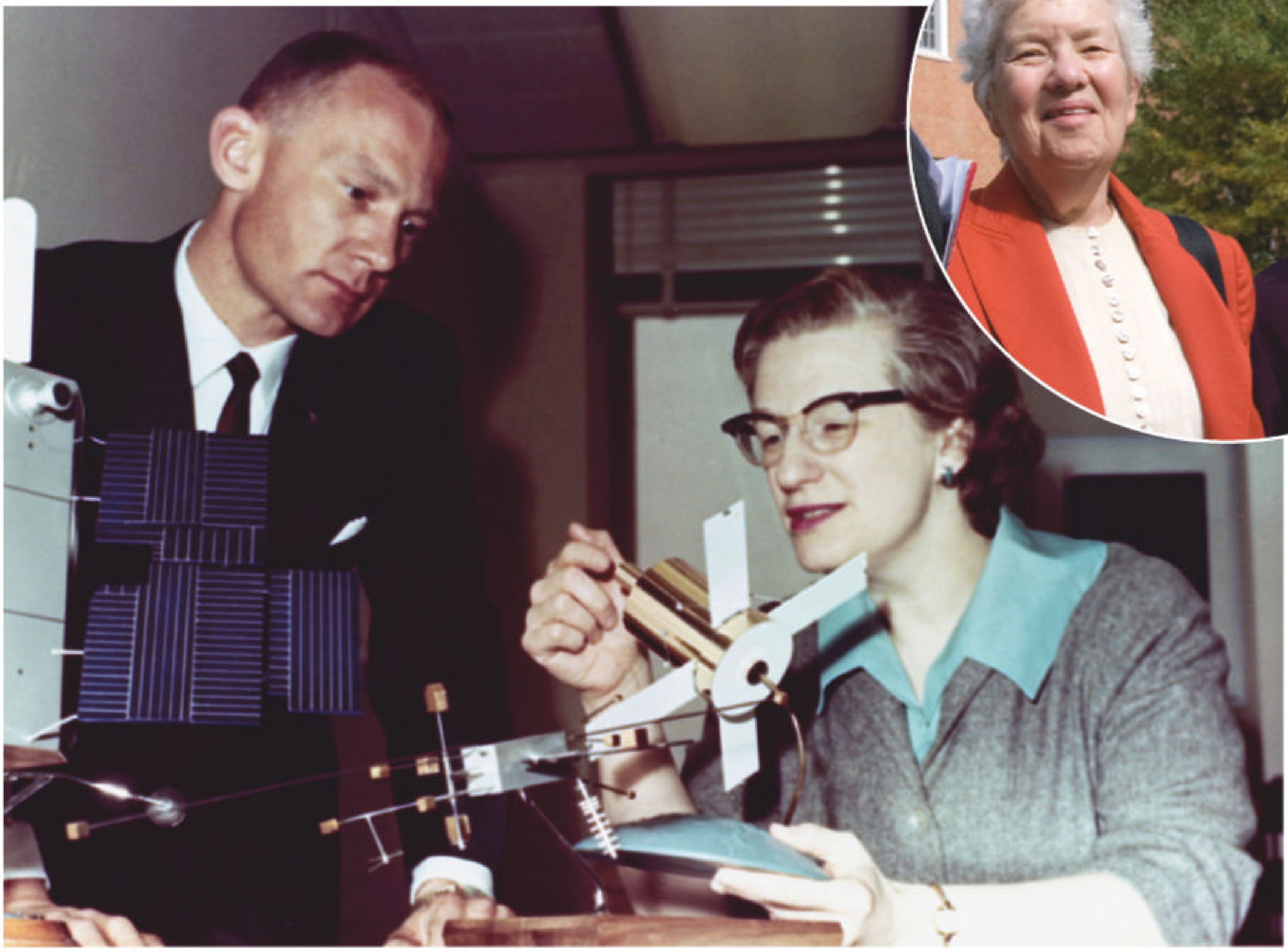
After earning her Ph.D. in 1949, Roman stayed on at Yerkes Observatory another six years as a researcher and instructor, but with much lower pay than her male colleagues. The department chairman, Nobel laureate Subrahmanyan Chandrasekhar, explained to her: "We don't discriminate against women — we can just get them for less."

Opening new frontiers

Despite these ongoing hardships, Rubin and Roman pressed on. They began to make names for themselves and, as it turned out, for two future telescopes.

After earning her Ph.D. in 1954, Rubin went on to become Georgetown faculty. She later moved to the Carnegie Institution in Washington, diving into research on galaxies that led

VERA C. RUBIN OBSERVATORY



ABOVE: Vera Rubin (left) and Nancy Grace Roman during the NASA-sponsored Women in Astronomy and Space Science 2009 meeting in Adelphi, Maryland. NASA, JAY FREIDLANDER

LEFT: In her role as chief astronomer, Roman shaped NASA's space astronomy program. This 1965 snapshot captures Roman as she discusses the Advanced Orbiting Solar Observatory with future moonwalker Buzz Aldrin. NASA

to her groundbreaking discovery of dark matter.

Roman moved from Yerkes to spend three and a half years at the U.S. Naval Research Laboratory, acquainting herself with the relatively new field of radio astronomy before taking the administrative position at NASA. There, Roman won her colleagues' respect as she relentlessly fought to give astronomers the tools they needed to probe the cosmos.

And astronomers anticipate the Rubin Observatory and Roman Space Telescope, like their namesakes, will make groundbreaking discoveries about our universe.

Each telescope will provide both wide-angle and pinpoint clarity in every image, and both are principally survey telescopes designed to create a catalog of sky objects and phenomena at unprecedented scales. They will each make much of their data available worldwide, free and in real time.

"I think we're entering a new paradigm of astronomical instant gratification," Nobel laureate Adam Riess of Johns Hopkins University recently said in an online webinar. Unlike the previously established method of discovering a few interesting objects and then spending months or years to requesting more time to observe them, he says, "to me, it's very exciting as a scientist that we're going to be able to dive right into everything we see without waiting."

That "we" includes the steadily increasing ranks of women in astronomy. As director of undergraduate studies and the first female professor in Princeton's astronomy department (where Rubin was long ago denied admission), astrophysicist Neta Bahcall is optimistic the trend will continue. Bahcall knew both women well; she was close friends with Rubin until her death in 2016.

"My main advice to young women in science is don't pay attention to the negative comments you get. Just do what you enjoy and what you're good at. Be resilient and persevere," she says.

"Nancy was tough as nails, and that's why she succeeded at NASA in getting things done," Bahcall says. "Vera just loved doing her science — taking data, looking at it herself and analyzing it. [She] always told me she wanted to find research that not that many people were working on. That's what she found most comfortable, not competing with everybody else."

Rubin said herself in a 1990 *Discover* magazine interview: "Fame is fleeting. My numbers mean more to me than my name. If astronomers are still using my data years from now, that's my greatest compliment."

Two of the decade's most powerful new telescopes will soon celebrate that spirit, showing just how far science has come in the past century, thanks to its extraordinary women.

Randall Hyman *is a journalist and photographer whose work has been featured in numerous publications, including* Smithsonian, Science, *and* The Atlantic.

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

A crescent Moon and three planets peek out from the early morning clouds above Bursa, Turkey. Most planetary observing this month is best done in the hours before sunrise. TUNÇ TEZEL

APRIL 2021

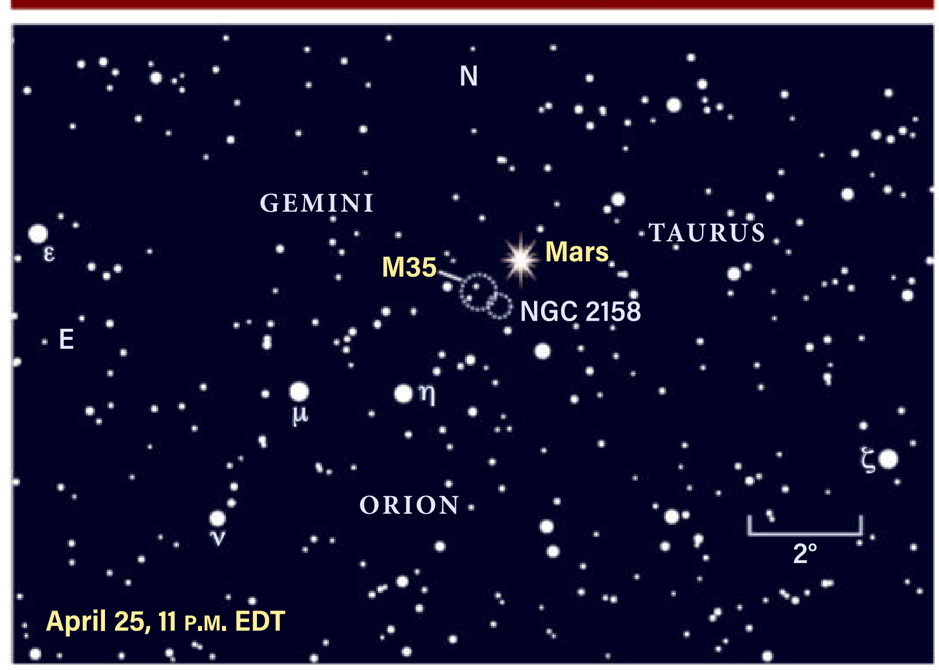
Mars rules the night

Planet viewing this month is limited to the evening and morning hours, with a broad stretch of nighttime devoid of major planets. Mars drifts through Taurus and into Gemini, while Mercury and Venus make a late April appearance. Jupiter and Saturn start the month in Capricornus, now appearing in the predawn sky. They climb higher as the month progresses.

Mercury passes through superior conjunction on the far side of the Sun April 18 and appears in the evening sky along with **Venus**, which passed through superior conjunction in late March. Both planets are slow to climb away from the Sun's glow.

On the last day of April, both planets hang very low in the western sky 30 minutes after sunset. Venus is most challenging at only 2° in elevation and sinking fast, but at magnitude –3.9 you can catch it perhaps 10 minutes earlier. If you do spot Venus, it's a useful guide to find fainter Mercury 4.5° above it. Mercury stands 6° high 30 minutes after sunset and glows at magnitude –1.2. It sets just after 9 P.M. local time. The visibility of both planets

Mars cozies up to two star clusters



Grab your binoculars April 25, when Mars passes 0.5° north of M35. Nearby is NGC 2158. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

MARS is the only planet visible most of the night. On April 25, it passes 0.5° north of M35, with NGC 2158 also visible nearby.

improves next month as they glide past the Pleiades star cluster (M45).

Mars lies high in the western sky after sunset, joining the stars of Taurus the Bull. It shines at magnitude 1.3 on April 1 and fades to 1.6 by the end of the month. Compare the Red Planet's signature orange-colored glow to Aldebaran, the Bull's magnitude 0.9 star. Aldebaran, a glowing star emitting its own light, appears reddish due to its "cool" surface temperature around 6,700 degrees Fahrenheit. But Mars is a cold, rocky planet and has no light of its own. Instead, its ruddy color occurs because it reflects sunlight preferentially in the red part of the spectrum, due to the makeup of its rusty surface material.

Mars tracks slowly through Taurus. Between April 12 and 13, it passes between the two stars marking the horns of the Bull — Alheka (Zeta [ζ] Tauri) and Elnath (Beta [β] Tauri). The planet crosses into Gemini April 24, then early on the 27th passes delightfully 0.5° north of M35, a fine open cluster in Gemini with a few colored stars. Grab a pair of binoculars to soak in this stunning sight, as well as pick up an additional target: Located just 0.5° southwest of M35 is an

— Continued on page 38

RISING MOON | A heartfelt sunrise

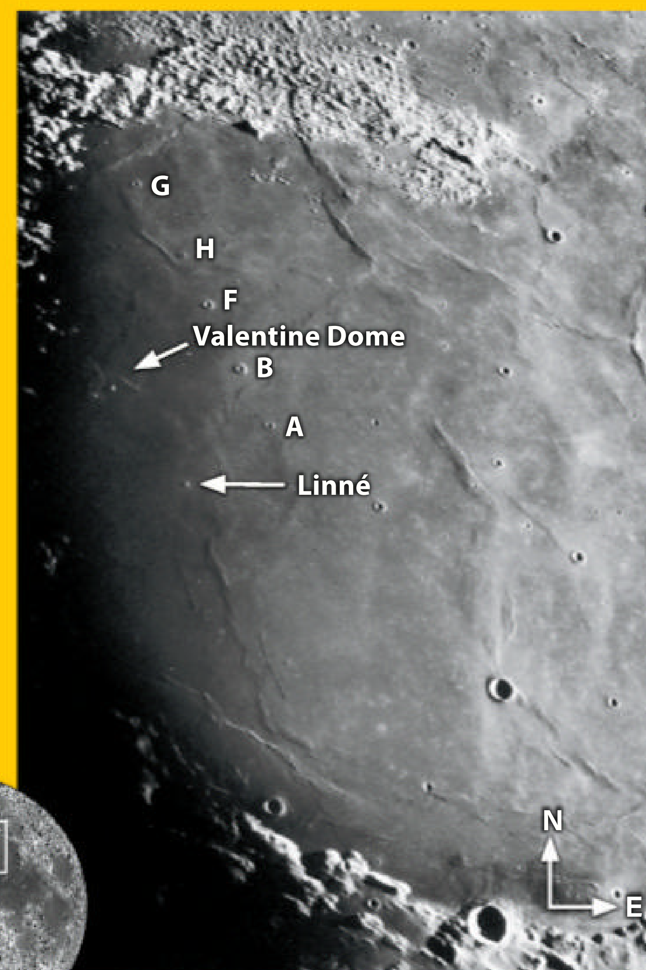
THE SEA OF SERENITY'S dark floor is strewn with pits, bumps and ridges when the Moon appears sliced in half. On the 17th, the snaking Serpentine Ridge captures our attention with its long play of light and dark across this huge impact basin just north of the lunar equator.

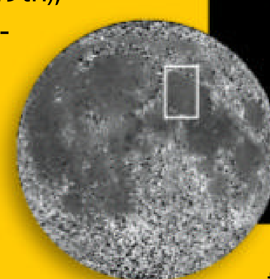
By the following night, the Sun has risen over the western half of Serenity's ancient lava-filled bowl, bringing to light some comparatively young craters. Strung out in a line from north to south are Linné G, H, F, B and A, with F and B the biggest at 3 miles (1.6 kilometers) across.

The Valentine Dome is a gentle volcanic protrusion tucked against the western flank of Serenity, visible only at the lowest of Sun angles. Timed perfectly for the 18th, its somewhat heart-shaped swelling crests less than 400 feet (122 meters) above the floor. You won't be able to miss the handful of older peaks sticking above the dome. One Earth night later (the 19th), the shade of the gentle slopes has disappeared under the higher Sun, leaving but a trace of the tiny tops.

The low angle returns at lunar sunset, when the Sun is shining from the Moon's west. This aptly named "reversed light" occurs about two weeks earlier on April 3, and again on May 2.

The Valentine Dome



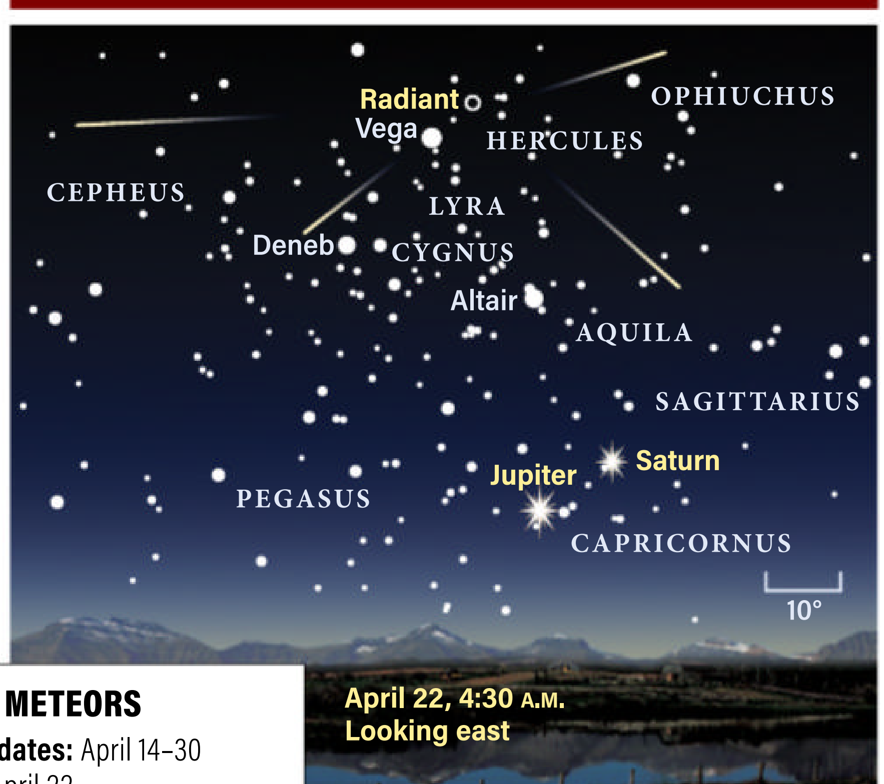


The heart-shaped Valentine Dome is a bit tricky to spot, but well worth the effort.

CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | A springtime show

Lyrid meteor shower



The Lyrids' radiant will reach 80° altitude around 4:30 A.M., slightly attenuating the shower's maximum rate.

LYRID METEORS

Active dates: April 14–30
Peak: April 22
Moon at peak: Waxing gibbous
Maximum rate at peak: 18 meteors/hour

THE SPRINGTIME LYRID meteor shower is like a welcome friend returning with the warmer weather. This annual shower is active from April 14 to 30 and peaks the morning of April 22. The radiant, located in the compact constellation Lyra the Harp, rises in the late evening and stands about 20° high at local midnight. A 10-day-old Moon will affect observations until it sets around 4 A.M. local time, offering an hour of dark skies before twilight begins. This early morning hour is the best time to view the shower, which can generate an average of up to 18 meteors per hour when the radiant is overhead. Most meteors are best seen from dark sites, well away from streetlights, and with dark-adapted eyes, which allow fainter members of the shower to be observed.

STAR DOME

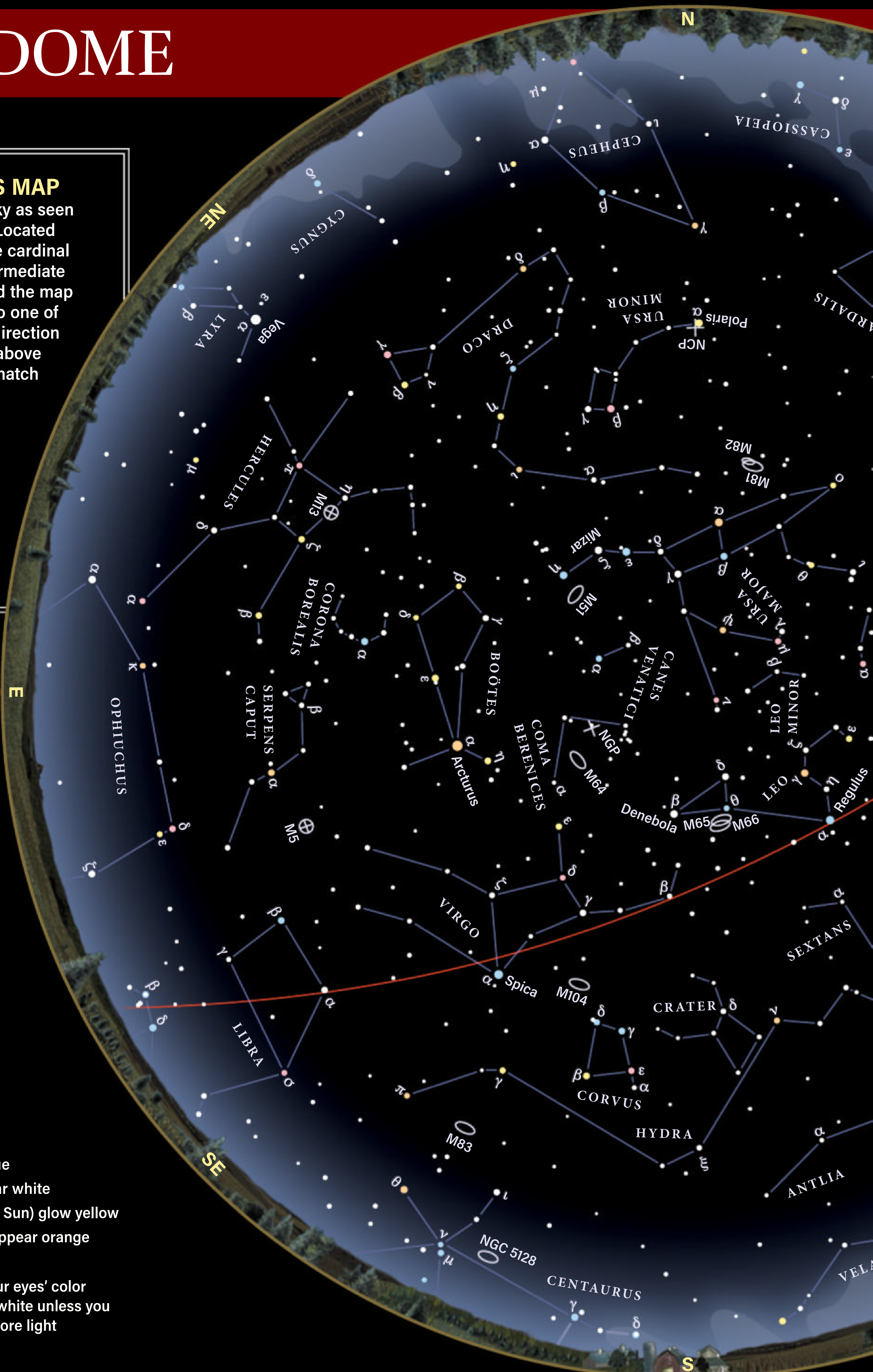
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight April 1
11 P.M. April 15
10 P.M. April 30

Planets are shown at midmonth



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

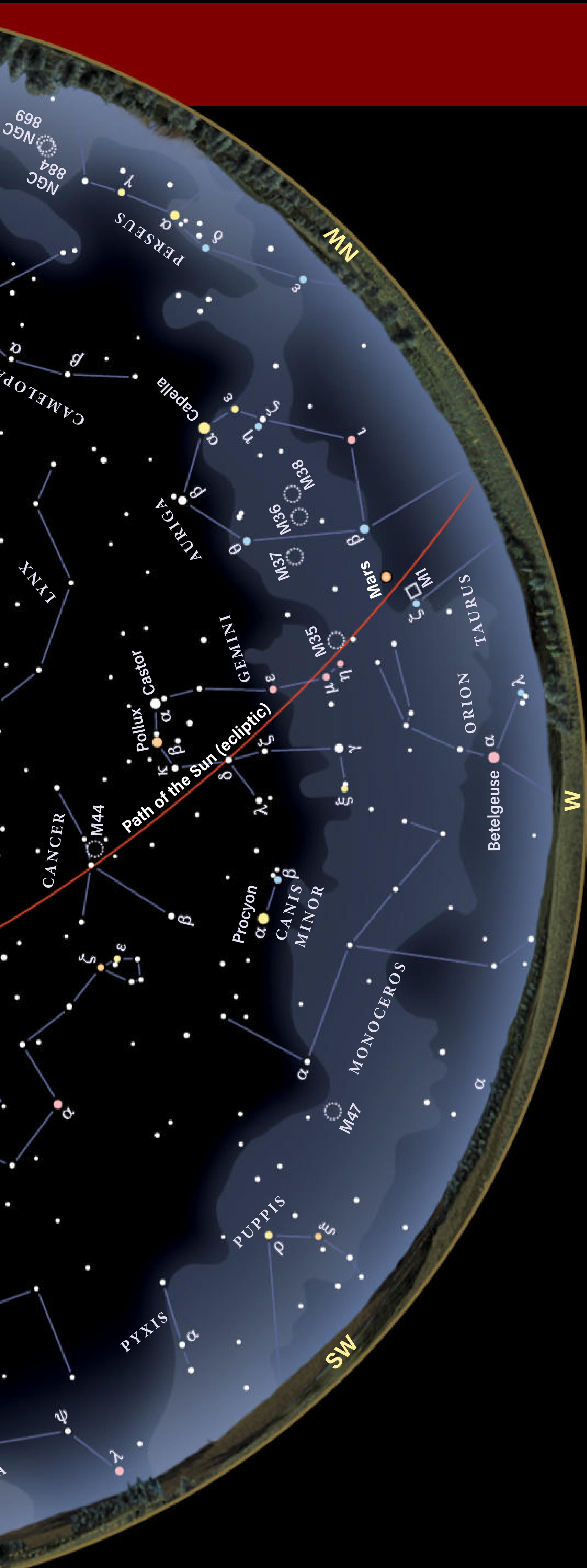
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



APRIL 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

4 Last Quarter Moon occurs at 6:02 A.M. EDT

Asteroid Metis is at opposition, 8 A.M. EDT

6 The Moon passes 4° south of Saturn, 4 A.M. EDT

7 Dwarf planet Ceres is in conjunction with the Sun, 3 A.M. EDT

The Moon passes 4° south of Jupiter, 3 A.M. EDT

9 The Moon passes 4° south of Neptune, 7 A.M. EDT

11 New Moon occurs at 10:31 P.M. EDT

12 Asteroid Juno is stationary, 10 P.M. EDT

13 The Moon passes 2° south of Uranus, 8 A.M. EDT

14 The Moon is at apogee (252,351 miles from Earth), 1:46 P.M. EDT

17 The Moon passes 0.1° south of Mars, 8 A.M. EDT

18 Mercury is in superior conjunction, 10 P.M. EDT

20 First Quarter Moon occurs at 2:59 A.M. EDT

22 Lyrid meteor shower peaks

Asteroid Vesta is stationary, 2 P.M. EDT

26 Full Moon occurs at 11:32 P.M. EDT

27 The Moon is at perigee (222,064 miles from Earth), 11:22 A.M. EDT

28 Pluto is stationary, 3 P.M. EDT

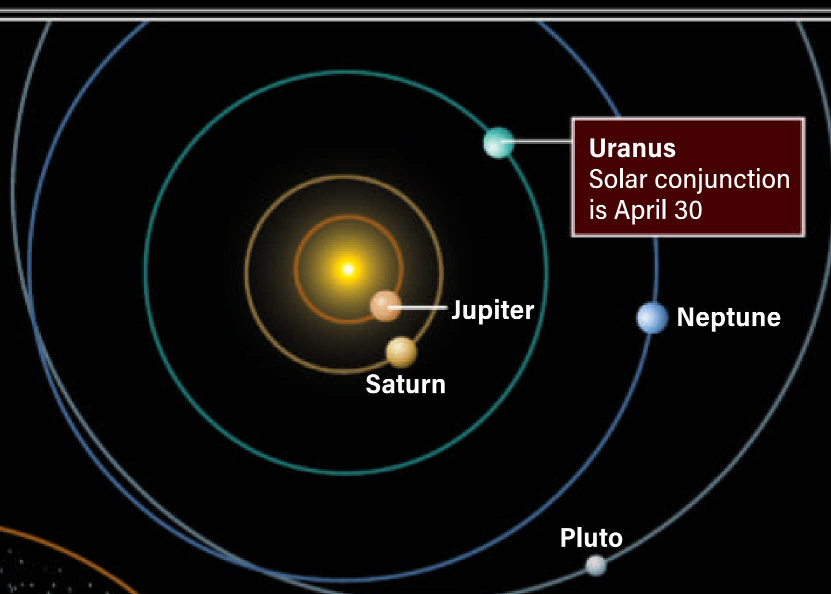
30 Uranus is in conjunction with the Sun, 4 P.M. EDT

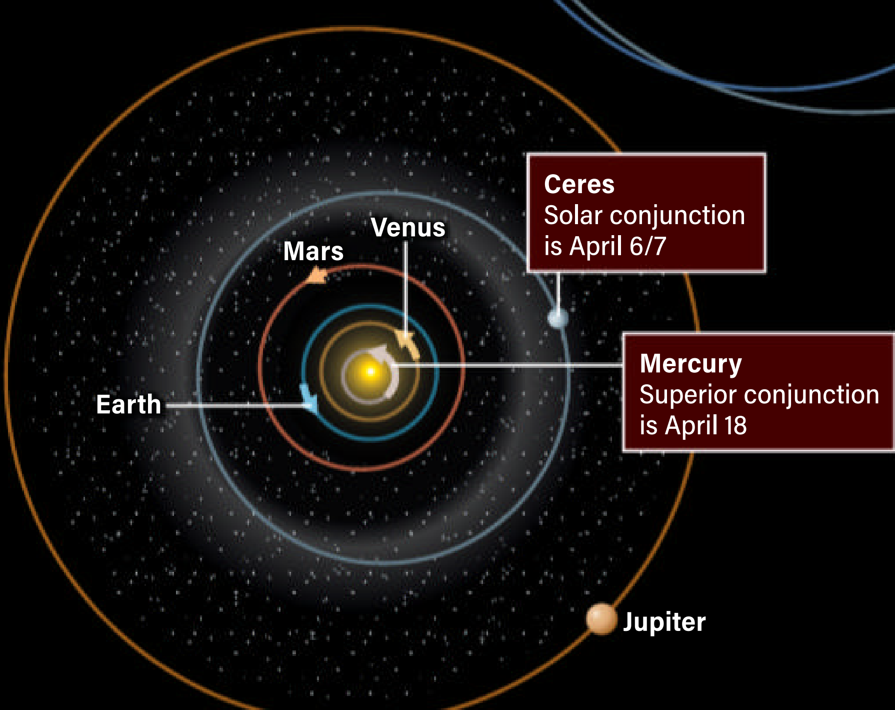
PATHS OF THE PLANETS

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

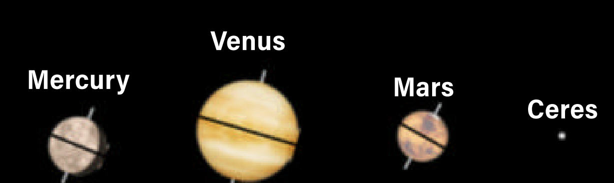
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



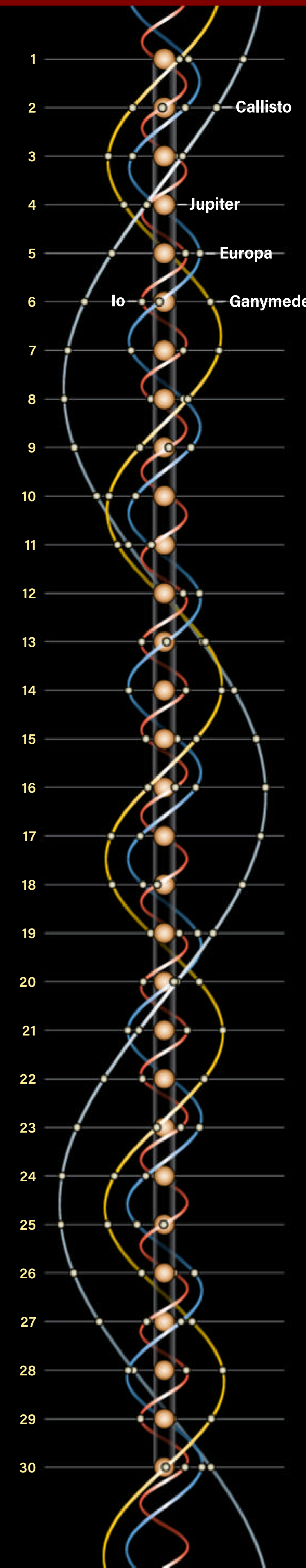
PLANETS	MERCURY	VENUS
Date	April 30	April 30
Magnitude	–1.3	–3.9
Angular size	5.6"	9.8"
Illumination	86%	99%
Distance (AU) from Earth	1.207	1.699
Distance (AU) from Sun	0.310	0.722
Right ascension (2000.0)	3h16.4m	3h04.8m
Declination (2000.0)	19°31'	16°58'

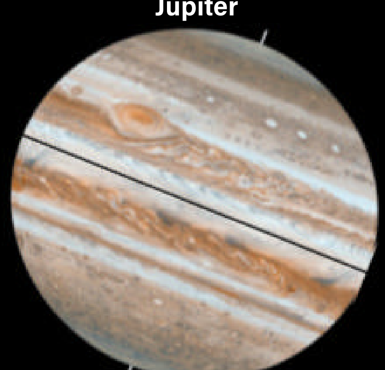
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

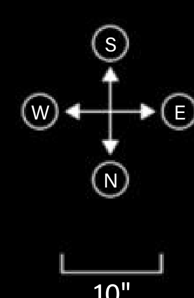
APRIL 2021

JUPITER'S MOONS

Dots display positions of Galilean satellites at 5 A.M. EDT on the date shown. South is at the top to match the view through a telescope.



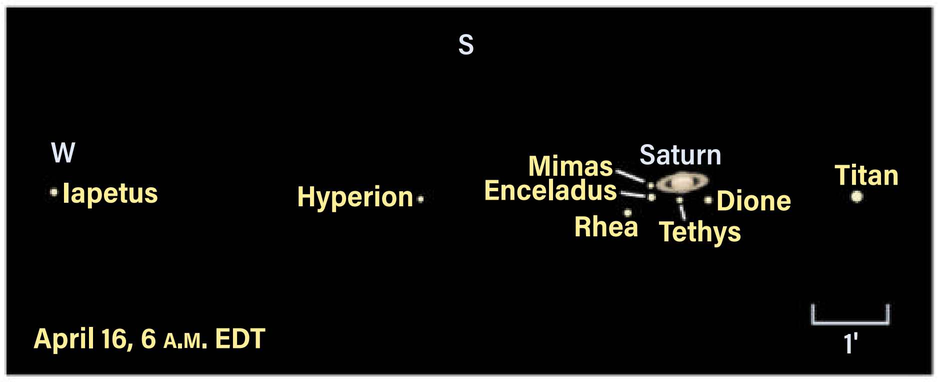




MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
April 15	April 15	April 15	April 15	April 15	April 15	April 15
1.4	9.0	–2.1	0.6	5.9	7.8	15.2
5.0"	0.3"	35.9"	16.3"	3.4"	2.2"	0.1"
92%	100%	99%	100%	100%	100%	100%
1.886	3.901	5.498	10.218	20.728	30.758	34.272
1.628	2.911	5.062	9.970	19.758	29.925	34.261
5h36.1m	1h26.0m	21h52.1m	20h58.7m	2h28.9m	23h30.9m	19h55.1m
24°48'	1°33'	–13°40'	–17°42'	14°16'	–4°19'	–22°13'

 — Continued from page 33

Bright Iapetus



On April 16, Saturn's moon Iapetus lies at its brightest due east of the planet, making it a good small scope target.

even more distant cluster, NGC 2158.

On April 30, Mars forms a nice triangle with the well-known 3rd-magnitude pair Eta (η) and Mu (μ) Geminorum. By now, Mars sets shortly after local midnight, so it's best to catch the planet soon after twilight for the best views. The disk spans only 5.3" on April 1 and slowly shrinks to 5" by the end of the month, so telescopic views are challenging at best.

Once Mars sets, it's more than four hours before another major planet rises. You can use the middle of the night to search for the brightest of all asteroids, 4 Vesta, which reached opposition in Leo the Lion last month. Vesta is an easy binocular object at 6th magnitude, now moving across the central region of Leo. Comparing its position on consecutive nights will reveal its motion relative to the background stars. On April 1, it's 2° due east of 51 Leonis. This star is most easily found by scanning midway between Algieba (Gamma [γ] Leonis) and Chertan (Theta [θ] Leonis). By mid-April, Vesta lies only 0.6° southeast of 51 Leonis; it then swings southward, ending the month just over 1° southeast of the star.

Saturn rises shortly after 4 A.M. local time on April 1 and stands more than 10° high at the onset of twilight. This is still quite low for good viewing conditions, but Earth's early-morning atmosphere is occasionally very steady before the heat of the day strikes it. Saturn shines at magnitude 0.6 all month. Viewing the ringed planet is possible toward the end of April because of its higher altitude (above 20°) as twilight begins. Since the planet has been out of view for a while due to conjunction with the Sun, check out its atmospheric features. Are there any new white spots?

> **2** Saturn's moon Iapetus changes brightness by 2 magnitudes, depending on the side facing Earth.

Even at low altitude, moons of Saturn can be spotted in small telescopes. Titan shines the brightest at magnitude 8.8. On April 1, it lies 2.6' due east of the planet. It orbits every 16 days, making about two orbits per month. Titan passes due south of the planet April 5 and 21, and due north of the planet April 13 and 29.

Iapetus is a challenging moon to spot, swinging between 10th and 12th magnitude as it orbits the

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)
Venus (west)
Mars (west)
Uranus (west)

MIDNIGHT
Mars (west)

MORNING SKY
Jupiter (southeast)
Saturn (southeast)
Neptune (east)

COMET SEARCH | Constellation crosser

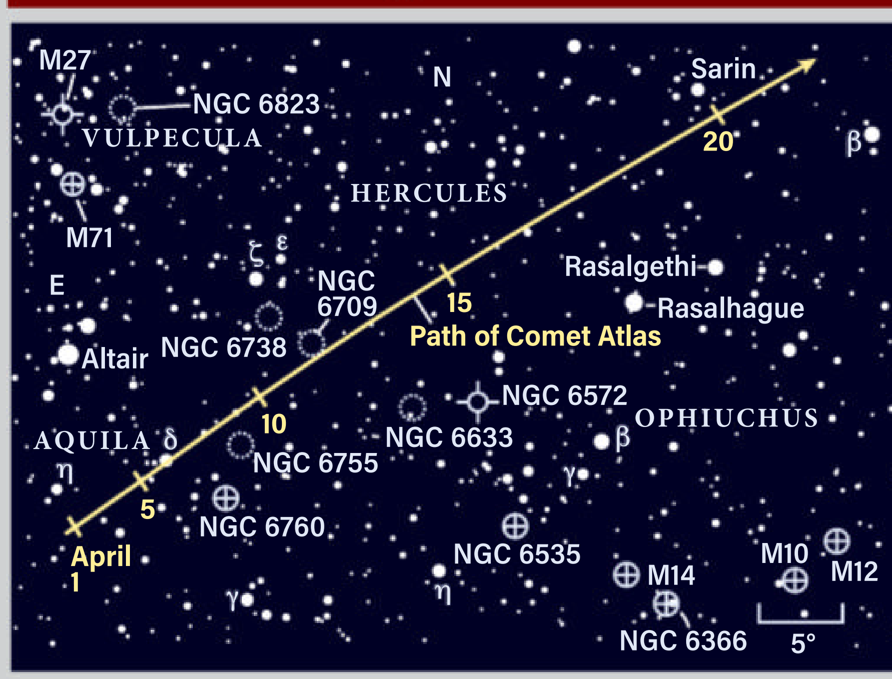
LIKE A SIDEKICK to the bright galaxies in the Coma-Virgo Cluster, Comet C/2020 R4 (ATLAS) makes a wonderful addition to the spring sky. It launches from a late-night perch in Aquila and flies into evening skies by month's end, its apparent speed due to the comet and Earth orbiting in opposite directions.

The late-night observing window opens on the 6th after 1 A.M. local time, with the best views coming before moonrise and the dawn, when ATLAS is higher in the sky and well above the horizon haze.

Lunar interference begins on the 19th, but by evening's astronomical darkness on the 29th, ATLAS is hoofing it out of Boötes and into galaxy country at 4° each night. The comet's brightness of 11th magnitude will depend on its dust and gas activity. Some detail is visible through an 8-inch scope for this typical appearance. Look for a northward-pointing dust tail with a sharp western flank; imagers should collect some blue or green ion emission.

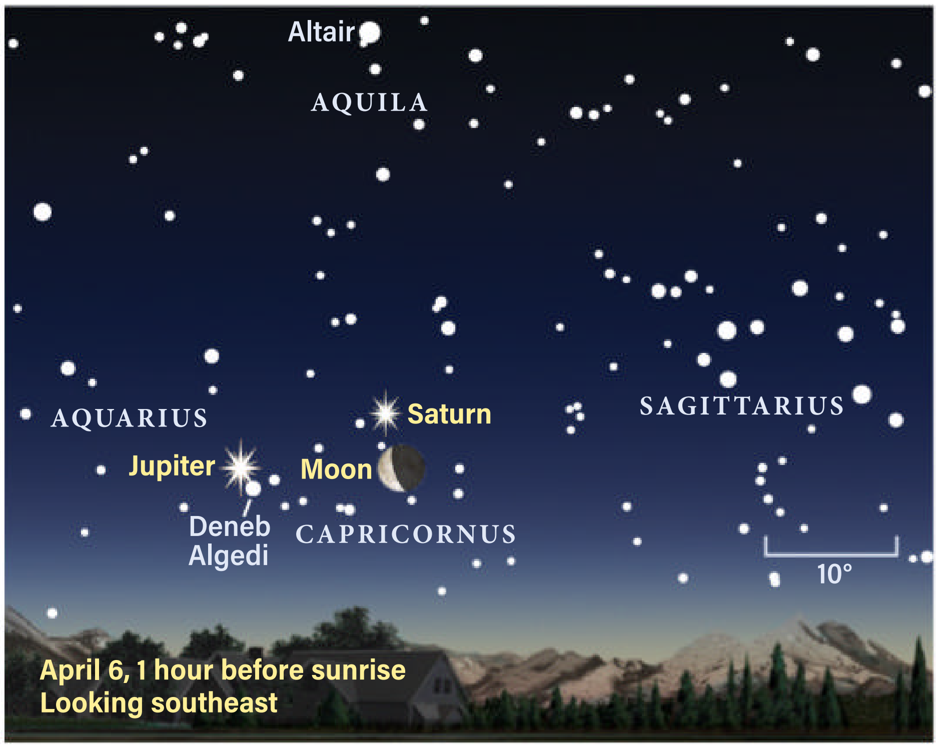
ATLAS' brightness will soon plunge, worsened by the increasing Earth-comet separation after its closest pass to our planet (0.46 astronomical unit [AU], where 1 AU is the average Earth-Sun distance) on the 23rd. If that pass had occurred three months later in ATLAS' nearly 1,000-year period, the geometry would have made it as bright as last year's C/2020 F3 (NEOWISE).

Comet C/2020 R4 (ATLAS)



This month's Messier marathons feature a Kuiper Belt arrival in front of the Milky Way's Great Rift in Aquila. Comet ATLAS covers a large swath of sky during April, passing a plethora of deep-sky objects on the way.

The Moon joins Jupiter and Saturn



Giant planets Jupiter and Saturn rise before the Sun this month. On April 6, a waning crescent Moon joins the pair in Capricornus.

planet — a result of the varying albedo (reflectivity) of its surface. Saturn's low altitude creates another challenge here. However, on April 16, Iapetus reaches its brightest western elongation, presenting a good opportunity to identify it with small telescopes. Iapetus lies 8' due east of Saturn, so use a low-power eyepiece with a field of view of at least 1/3° to search for the moon.

Jupiter rises 35 minutes after Saturn in early April, shortly before 5 A.M. local time. It lies in the northeastern part of Capricornus. On April 7, it stands 2° due north of Deneb Algedi (Delta [δ] Capricorni). Jupiter brightens by 0.1 magnitude to –2.2 during the month and treks eastward, crossing into Aquarius on April 25.

The best telescopic views are later in the month, when the giant planet has time to rise higher in the sky. It reaches 18° in elevation in the southeastern sky by 5 A.M. local time on April 30, just as dawn begins to break — a great time to check out atmospheric features on the 37"-wide disk. Its four Galilean moons wander around the planet in various intervals, and their changing positions are fascinating to track.

As Jupiter rises on April 9, Io is already transiting the disk. The moon is preceded by its dark shadow, farther west on the planet's face. Io's shadow slips off the disk at 6:28 A.M. EDT, visible in darkness across the U.S. But only those in western locations will be able to watch Io make its way off the western edge of the disk an hour later. There are many more transits and occultations throughout the month.

Between now and August, when Jupiter reaches opposition, the gas giant will climb higher in the eastern sky each month, gaining altitude and offering improved conditions for observing.

Neptune rises at the break of twilight at the end of April, having passed through superior conjunction in March. By 5:30 A.M. local time, the planet stands 10° high in the eastern sky, nearly 5° east of 4th-magnitude Phi (ϕ) Aquarii. Neptune is dim at magnitude 7.8; if you're lucky, you can catch it before the sky brightens. Its visibility will improve through the summer.

Uranus is in conjunction with the Sun April 30 and only briefly visible low in the evening sky early in the month.

Martin Ratcliffe *is a planetarium professional and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

GET DAILY UPDATES ON YOUR NIGHT SKY AT
www.Astronomy.com/skythisweek.

LOCATING ASTEROIDS |
A walk in the park

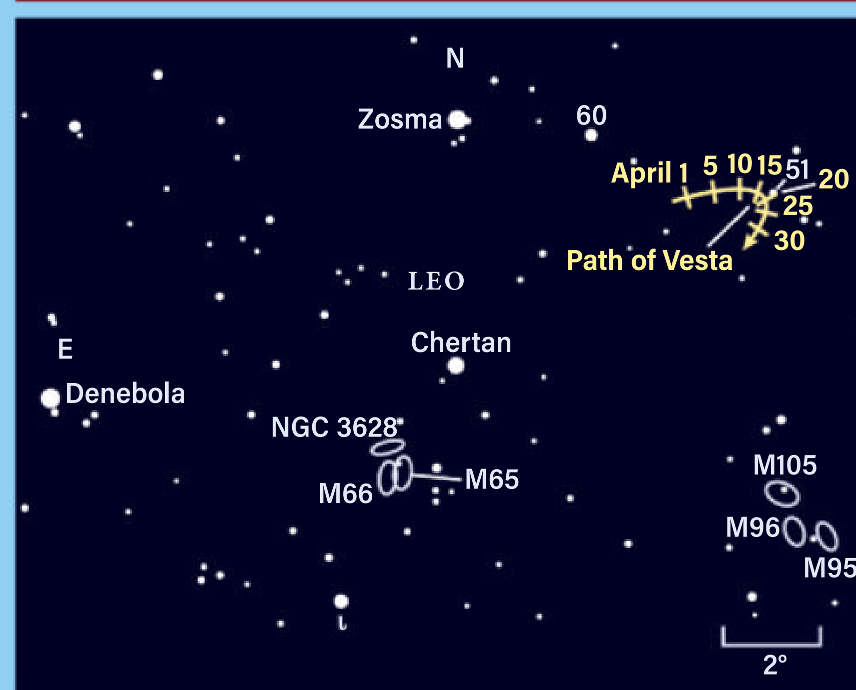
SIMPLE, RELAXING ASTEROID TRACKING like this happens only every three years or so. This month, asteroid 4 Vesta shines at magnitude 6.6, easy pickings with binoculars from the city. Its background constellation of Leo is recognizable from light polluted areas, with the blue-white luminary Regulus leading it high in the southeast. Combine this with mild spring evenings and it rarely gets better for asteroid watchers.

After two or three sightings, you won't even need a chart to find it. For the first search, though, use our chart to guide you to the spot near Leo's hindquarters, notable for its perfect right-angled triangle. In a logbook or on a blank sheet or paper, place the brightest six dots with a pencil. Create a large version so you have enough room to add Vesta's slow shift every three or four nights.

A typical amateur won't be able to detect Vesta moving during one observing session this month because it appears to slow down and turn in a tight curve. Earth passed it by on our faster inside track, causing this part of a retrograde loop. The bright light of the waxing gibbous Moon on the 21st through the 23rd interferes, so give these nights a pass.

Spanning 310 miles (499 km), Vesta is a large object in the main asteroid belt, second only to dwarf planet 1 Ceres.

Making the turn



Asteroid Vesta is easy to spot this month as it makes a quick turnaround in Leo the Lion.

SEE SPRING'S BEST

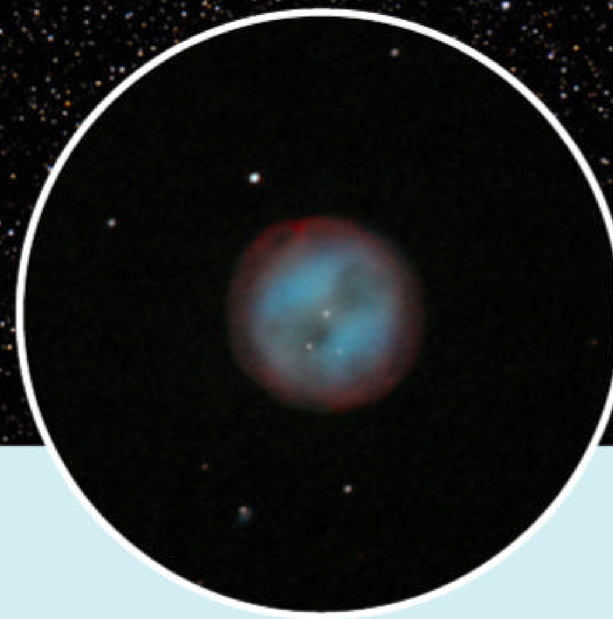
Messier objects

Here's a list of 25 targets to help you make the most of your evening. BY MICHAEL E. BAKICH

BERNHARD HUBL

M5 is the brightest globular cluster in the northern sky. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

The Orion Nebula, M42, is perhaps the most famous deep-sky object and the closest major star-forming region — just 1,500 light-years away. MADHUP RATHI



The Owl Nebula is one of the four planetary nebulae that Messier cataloged. JOHN CHUMACK

Charles Messier was a French comet-hunter who occasionally spied objects masquerading as comets due to their fuzzy appearance through his small scope. But they didn't move against the starry background like comets did, so he documented them to avoid confusion. Over time, his list grew to 109 deep-sky objects, encompassing what we now know to be galaxies, nebulae, and star clusters.

Messier's objects are not spread out evenly across the sky, so a window exists from mid-March to early April when observers in the Northern Hemisphere can catch them all in a single night. This feat is called a Messier marathon, an activity that's been popular with astronomy clubs since the 1980s.

Many observers have nabbed all 109 objects in one night. But what if you can't devote a whole night to the hunt? Then spring for the Messier mini-marathon, 25 great objects you can see between the fall of darkness and midnight.

Start with the first object on the list; it will be farthest west, so the following objects will set one after the another, in order, giving you more time to observe them.

In 2021, the Moon is New on March 13 and April 11. So, your first observing window is from the date you get this magazine until around March 16. Starting on the 17th, moonlight will interfere with your search until Last Quarter, which occurs April 4. Then the sky will stay Moon-free until past midnight for another week, marking your second observing window.

Let your scope cool to the ambient temperature, take your time with each object, and have fun!

OPPOSITE: The dust lanes that thread the arms of M63 are some of the most intricate details in all of Messier's catalog. ANDREAS ELEFTHERIOU

M38: The Starfish Cluster in Auriga glows at magnitude 6.4. Through a 4-inch telescope, you'll spot 30 stars in an area 20' across. Although this region's background is rich, the cluster stands out well. Crank up the magnification and you'll identify several nice chains of stars. While you're there, be sure to look 0.5° south of M38 for another open cluster, NGC 1907.

M1: The Crab Nebula in Taurus is a supernova remnant with a high surface brightness, so even a 3-inch scope will reveal it. It shines at magnitude 8.0 and its oval shape, measuring 6' by 4', is oriented northwest to southeast. To find it, start at 4th-magnitude Zeta (ζ) Tauri and move 1° northwest of the star.

M36: The Pinwheel Cluster shines at magnitude 6.0. With a 4-inch scope, several dozen stars will be visible strewn across an area 12' wide. Insert an eyepiece that gives a magnification around 100x and see if you can spot a pinwheel-like pattern in this cluster's stars.

M42: The Orion Nebula may be the sky's No. 1 object. Any scope will reveal nebulosity here, plus a tiny cluster of stars called the Trapezium. Although you don't need a nebula filter, using one from a dark location accentuates the contrast between the light and dark regions.

M37: The Salt and Pepper Cluster in Auriga shines at magnitude 5.6 and displays an even distribution of stars not found in many other clusters. Although it sits squarely within the Milky Way, M37's borders are easy to discern. A 3-inch scope reveals 50 stars

within a 20'-wide circle. The brightest member — a magnitude 9 orange star — sits near the cluster's center.

M35 lies 2.3° northwest of magnitude 3.3 Eta (η) Geminorum. From a dark site, you'll spot the magnitude 5.1 cluster easily without optical aid. Point a telescope at it and you'll see a second open cluster, NGC 2158, at magnitude 8.6. M35 contains two dozen stars brighter than 9th magnitude. Near the cluster's center, look for a string of stars shaped like a saxophone.

M41: This is an easy target because it lies 4° south of Sirius (Alpha [α] Canis Majoris). It glows at magnitude 4.5 and measures 38' across. Through a 6-inch scope, you'll see about 50 stars. At first glance, this cluster appears roughly circular. Closer inspection reveals several chains of stars running north-south.

M50: The Heart-Shaped Cluster shines at magnitude 5.9 in Monoceros. Through a small scope at 100x, you'll spot 50 stars in an area 16' across. The brightest glows at 8th magnitude. The cluster's common name refers to how the oval-shaped central region appears to connect with two trails of stars that move outward.

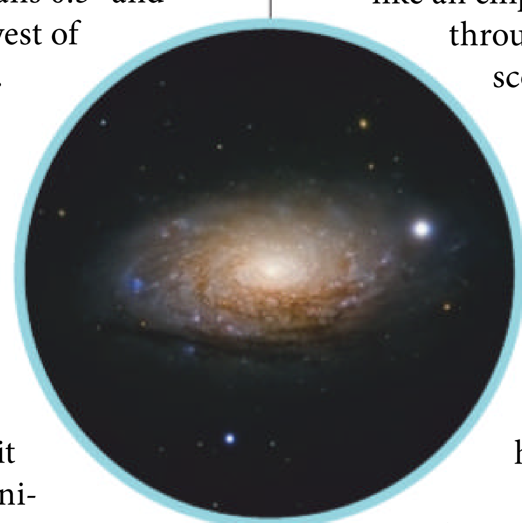
M47: You'll see this open cluster easily from a dark site without optical aid. It lies in Puppis, 5° south-southwest of Alpha Monocerotis. At magnitude 4.4, M47 ranks as the sky's 14th-brightest open cluster. Most of that brightness comes from just six stars, which lie in a field of about 75 others.

M46: This magnitude 6.1 open cluster in Puppis contains several hundred stars, 100 of which are visible through an 8-inch scope. They appear evenly distributed throughout a circle slightly less than half a degree across. Within the boundaries of M46 resides planetary nebula NGC 2438. It sits 7' north of the cluster's center and measures about 1' across. Distance measurements place NGC 2438 several thousand light-years closer than M46.

M48: This open cluster in Hydra shines at magnitude 5.8, measures nearly 1° across, and lies 3° south-southeast of Zeta Monocerotis. A 6-inch scope reveals about 75 stars. Look for a zigzag chain of 9th- and 10th-magnitude stars running south-southwest to north-northeast through the cluster's center.

M44: The Beehive Cluster in Cancer glows at magnitude 3.1 and spans 1.5°. M44 looks best through binoculars with magnifications between 10x and 16x. The Beehive's brightest star is magnitude 6.3 Epsilon (ε) Cancri. Some 80 of the cluster's stars are brighter than 10th magnitude.

M67: The other open cluster in Cancer is M67, magnitude 6.9. It spans 0.5° and lies 1.7° due west of Alpha Cancri. Through a 4-inch scope, you'll spot roughly two dozen stars. Note the yellow star on its northeastern edge; it shines at magnitude 7.8 but is not a member of the cluster.



M81: At magnitude 6.9, Bode's Galaxy is one of the sky's brightest galaxies. It's also big — 24' by 13'. You'll find it 2° east-southeast of 24 Ursae Majoris. Through an 8-inch scope, a large, bright central region surrounds the much brighter core, and a 12-inch scope will show you how the spiral arms wind around it.

M82: The Cigar Galaxy glows at magnitude 8.4, measures 12' by 5.6', and lies 0.5° due south of M81. M82 appears four times as long as it is wide, oriented east-southeast to west-northwest. The galaxy's brightest part lies east of center and a dark lane cuts diagonally across its minor axis.

M97: One of the best springtime planetary nebulae is the Owl Nebula, which shines at magnitude 9.9 and spans 3.3'. Look for its "eyes," two dark, circular regions in its disk. An Oxygen-III filter and a magnification of 100x work best. M97 lies 2.3° southeast of Merak (Beta [β] Ursae Majoris).

M104: The Sombrero Galaxy in Virgo looks like a bright lens split by a dark dust lane. Through a 4-inch scope, the lane shows up only near the center. The core is bright, with a large halo surrounding it. M104 glows at magnitude 8.0 and measures 7.1' by 4.4'. Find it 5.5° north-northeast of Delta (δ) Corvi.

M94: This magnitude 8.2 spiral galaxy lies 3.2° east of Beta Canum Venaticorum. It spans 13' by 11' and looks like an elliptical galaxy through small scopes. Through an 8-inch scope, you'll see the tiny nucleus surrounded by a bright disk with a much fainter oval halo around it.

M53: To find this magnitude 7.7 globular cluster, look a little less than 1° northeast of Alpha Comae Berenices. Through a 4-inch scope under a dark sky, you'll see several dozen faint stars in a 12.6'-wide circle, many of which concentrate in the bloated core.

M63: The Sunflower Galaxy, 5° northeast of Alpha Canum Venaticorum, shines at magnitude 8.6 and measures 13.5' by 8.3'. Through small scopes, the nucleus appears stellar, and a 3' long oval halo surrounds it. Through a 10-inch scope, the halo shows clumps made of star-forming regions in M63's spiral arms.

M51: The Whirlpool Galaxy in Canes Venatici lies 3.6° southwest of Eta Ursae Majoris, glows at magnitude 8.4, and measures 8.2' by 6.9'. It also has a smaller companion, NGC 5195. You'll see M51's spiral arms through an 8-inch scope. Look for the thin, dark dust lanes that follow the arms' inner edges. Also try to spot the apparent connecting arm between M51 and NGC 5195.

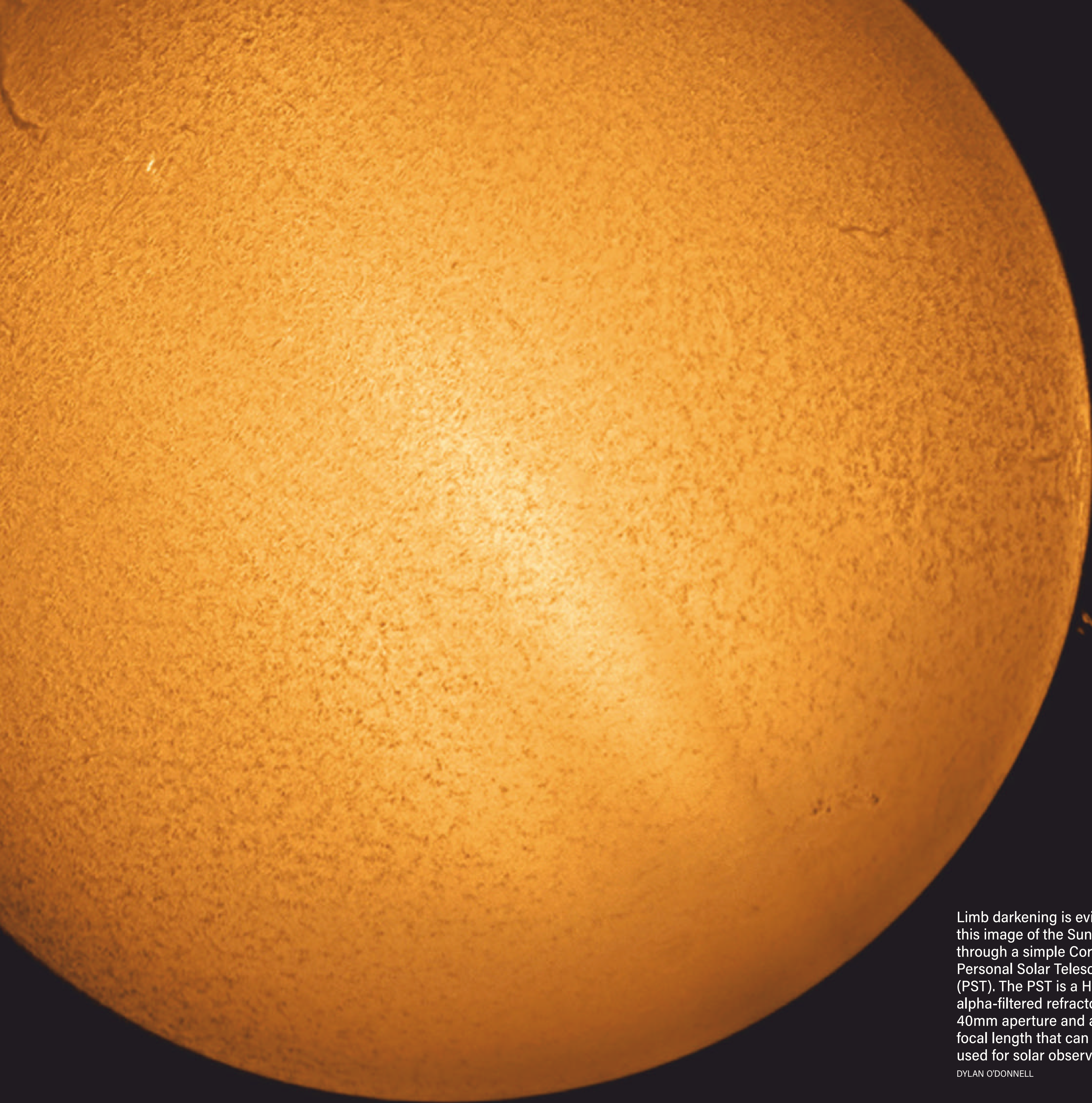
M83: The Southern Whirlpool Galaxy lies 7.2° west-southwest of Pi (π) Hydrae. It appears nearly face-on, so you'll see its spiral structure through scopes with apertures as small as 6 inches. The core is compact and round, and both spiral arms are easy to see, but the one that wraps southward from the bar's northeastern end shows up better. M83 shines at magnitude 7.5 and measures 15.5' by 13'.

M3: This magnitude 6.3 globular cluster lies midway between Arcturus and Cor Caroli in Canes Venatici. Through a 4-inch scope, the cluster has a wide, bright center that accounts for about half of its 16.2' width. Surrounding the center are dozens of stars whose density gradually decreases with distance.

M5: This globular cluster in Serpens lies 11.5° due north of Beta Librae. It glows at magnitude 5.7 and spans 17.4'. Through a 4-inch scope at 150x or more, you'll see a grainy structure and several dozen stars around the core. An 11-inch scope reveals more than a hundred stars.

M13: The Hercules Cluster is the fuzzy "star" two-thirds of the way from Zeta to Eta Herculis. Through 8-inch and larger scopes, you'll see hundreds of stars in a 16'-wide circle. Crank your magnification to 200x or more and try to see the propeller, a small Y-shaped region of three dark lanes near M13's center.

Michael E. Bakich *is a contributing editor of* Astronomy *who has run Messier marathons since the mid-1970s.*



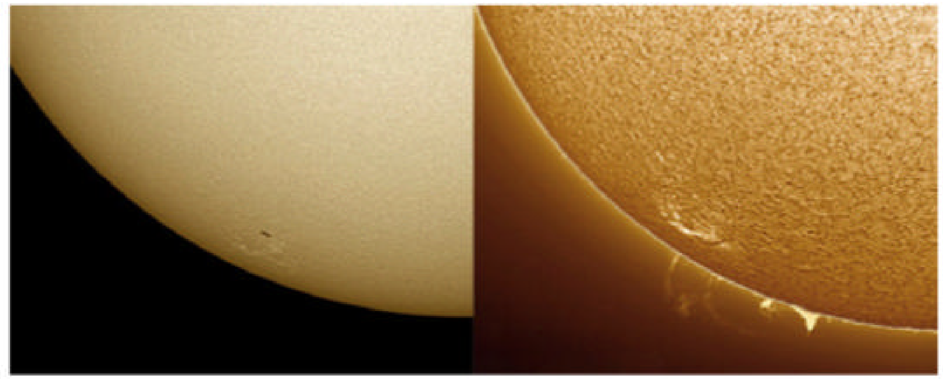
Limb darkening is evident in this image of the Sun viewed through a simple Coronado Personal Solar Telescope (PST). The PST is a Hydrogen-alpha-filtered refractor with a 40mm aperture and a 400mm focal length that can only be used for solar observing.
DYLAN O'DONNELL

FILTERS for observing

Whether using a telescope or binoculars, solar filters can help you view the Sun in its best possible light. BY PHIL HARRINGTON

FOR MANY, ASTRONOMY IS A LATE-NIGHT PURSUIT. We anxiously wait for Sol to set and twilight to fade before we begin to enjoy the sky. But by doing so, we are missing an amazing matinee every day — one performed by the Sun.

Our star is the perfect target for observers. No chart is needed to find it. You can't beat it for convenience. And light pollution doesn't even enter into the equation. With the Sun, there's no need to pull an all-nighter. Best of all, it is always changing. While most distant deep-sky objects appear static over the course of a human lifespan, the Sun changes every day. That makes it exciting to watch!



These images, taken only 5 minutes apart, show the same part of the Sun's disk on September 22, 2009. The photographer took the left shot through a visible-light filter and the right shot through a Hydrogen-alpha (Hα) filter. Note the additional features visible through the Hα filter. DAVID TYLER

But in order to enjoy the show, you need to come prepared. The Sun is the only celestial object that can easily do you harm. The same solar rays that cause sunburn will also burn your eyes' retinas — at least, without proper precautions. We hear these warnings from our parents when we're young and in the news before every solar eclipse: Never look directly at the Sun. So, in order to safely practice solar viewing, you'll need the right equipment.

Most experienced Sun-watchers prefer specially designed solar filters that reduce the Sun's energy to harmless levels. Filters come in two main categories: First are white-light filters. These block 99.999 percent of sunlight to allow us to see the Sun's visible surface, or photosphere, revealing wonderful views of constantly evolving sunspots. Second are Hydrogen-alpha (Hα) filters. These block all wavelengths of sunlight except for one — the wavelength emitted by hot hydrogen atoms. Hα filters reveal details on the Sun that are invisible using white-light filters, including flamelike prominences and intricate bright threads called solar plages, which are usually found near sunspots.

White-light filters

Known as "aperture filters," white-light filters fit over the front of a telescope in order to reduce the Sun's energy to a safe level before it enters the optical system, including your eyes. They are commonly made from glass or a polymer material, such as Mylar, and fit securely on a telescope or binoculars (although you will need two filters for the latter, one per barrel).

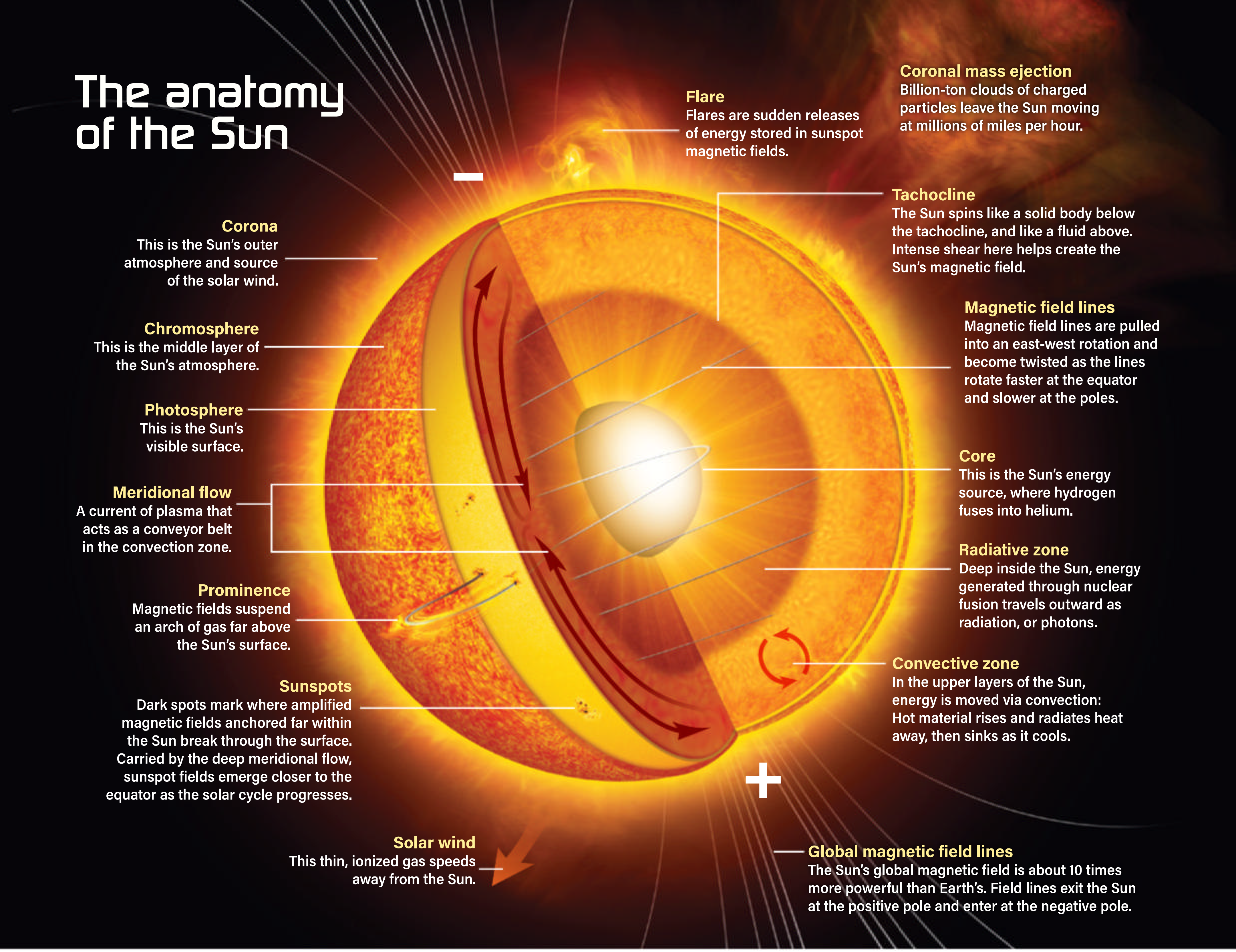
White-light filters should only be purchased from a reputable source. Some of the most popular include Astrozap (astrozap.com), Baader Planetarium (astrosolar.com/en), Celestron (celestron.com), Explore Scientific (explorescientificusa.com), Kendrick Astro Instruments (kendrickastro.com), Meade Instruments (www.meade.com), Orion Telescopes (www.telescope.com), and Thousand Oaks Optical (thousandoaksoptical.com).

You can purchase a premade filter mounted in a cell and sized to fit over the front

RIGHT: A Coronado PST, a common Hα telescope, is attached to an alt-azimuth GoTo mount in this setup — enabling quick and easy solar observing. WIKIMEDIA COMMONS/XOFC

BELOW: White-light filters, like this one from Thousand Oaks Optical, block all wavelengths of light equally, dimming the Sun enough to reveal sunspots. THOUSAND OAKS OPTICAL

the Sun



This illustration highlights some of the Sun's most striking features, many of which you can easily view using the right equipment. *ASTRONOMY*: ROEN KELLY

of your specific telescope, or you may prefer to buy a sheet of polymer filter material and make your own. To make a homemade filter cell, look for Baader AstroSolar Safety Film 5.0, then visit Baader's website for detailed instructions on how to construct the cell. Be sure to purchase a filter specified as neutral density (ND) 5.0, not ND 3.8. The latter is designed for photography and is not safe for visual observations.

Before using the filter, make sure to check that it's still performing properly. While some filters are made to resist scratches, it's better to be safe then sorry. To check whether your filter is safe, simply turn on your phone's flashlight and shine it directly behind the filter. If you only see a dim shine, you should be safe. But if you see particularly bright spots or streaks, your filter is damaged and should not be used.

Depending on filter coating, the Sun will appear a different color. Most glass filters create a yellow-orange tint, while many polymer filters provide a white image with a hint of blue.

White-light solar filters let you confirm that the Sun is alive and well, as groups of sunspots trek across its photosphere. These dark blemishes mark regions where disturbances in the Sun's powerful magnetic field hamper the convective flow of energy from deep within. As a result, that area of the Sun's surface cools slightly compared to its surroundings. The temperature of the photosphere is 9,900 degrees Fahrenheit (5,500 degrees Celsius), while sunspots are cooler, ranging between about 4,900 F and 7,600 F (2,700 C and 4,200 C). So, sunspots have roughly the same temperatures as the surfaces of the giant, puffy stars Betelgeuse and Antares. But because sunspots are cooler and dimmer than their surroundings, they appear dark through our filters. If you could surgically remove a sunspot and place it alone in the sky, it would appear crimson in color and shine brighter than the Full Moon.

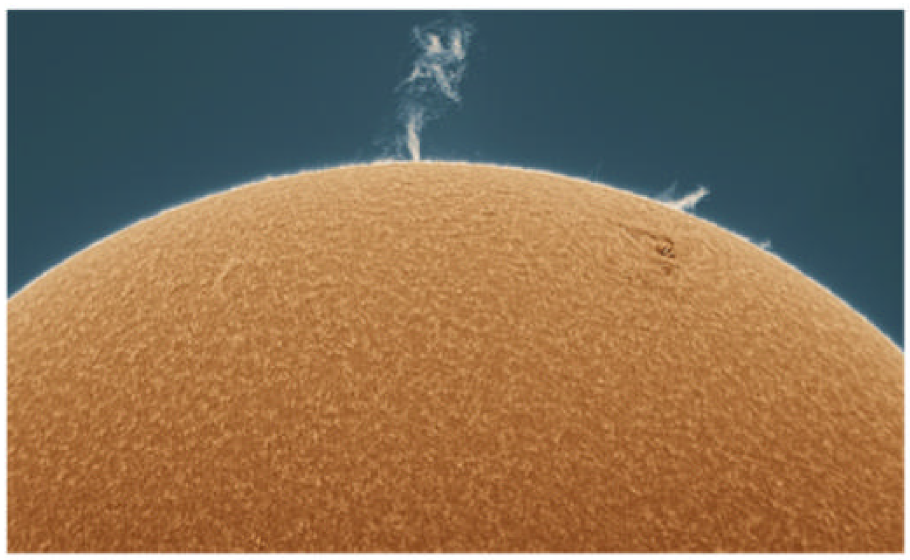
Sunspots can range in size from hundreds to thousands of miles in diameter. Some are large enough to be seen through binoculars — and even with the unaided eye, using proper filtered glasses — but most require a telescope. At magnifications of 50x or more, sunspots reveal two sections. The darker,

cooler central portion is called the umbra, while the surrounding lighter ring is called the penumbra. The Sun's magnetic field lines are perpendicular to the surface within the umbra, while they are angled more obliquely within the penumbra.

Sunspots appear in rapidly evolving groups that typically consist of one or two larger spots surrounded by several smaller members. These groups can transform within hours or days. It's fun to sketch or photograph their appearances every few days over a month or more. You'll be amazed at how much they change in size and shape. By tracking them for several months, you'll also notice that spots at different latitudes on the Sun move at different speeds. The Sun's equator rotates once every 25 days, while the north and south polar regions take approximately 36 days to complete a full rotation.

You might even begin to notice bright patches near sunspots. Those are called faculae, Latin for "little torch." Faculae occur above the photosphere

The Sun displays a slew of stunning features when viewed through a Hα filter, as seen here. JOHN CHUMACK



A flare extends from the surface of the Sun on August 15, 2016, captured here using an Hα filter. MICHAEL P. CALIGIURI

and are best seen along the edge, or limb, of the Sun, where their contrast is enhanced thanks to an effect called limb darkening. Limb darkening is the result of us seeing cooler, dimmer gas in the outer layers of the Sun as we look along the solar limb, instead of the hotter gas that we see deeper inside the Sun when we look directly at its central region.

The Sun's photosphere may appear smooth at first, but up close, we see it is comprised of countless tiny grains called granules. Each granule, measuring a little larger than Texas, is a convective cell of heated plasma. As the plasma rises to the top of the photosphere, it cools. This causes it to sink back into the photosphere, where it's reheated and recirculated, like a pot of boiling water. Because solar granules appear so tiny from our distant vantage point, resolving them requires at least a 3-inch telescope, 150x magnification, and very steady seeing conditions.

And, of course, white-light filters are ideal for viewing the partial phases of solar eclipses. The countdown is on for the next Great (North) American Eclipse on April 8, 2024, and people are already making plans. One thing's for sure: Solar filters are on everyone's list.

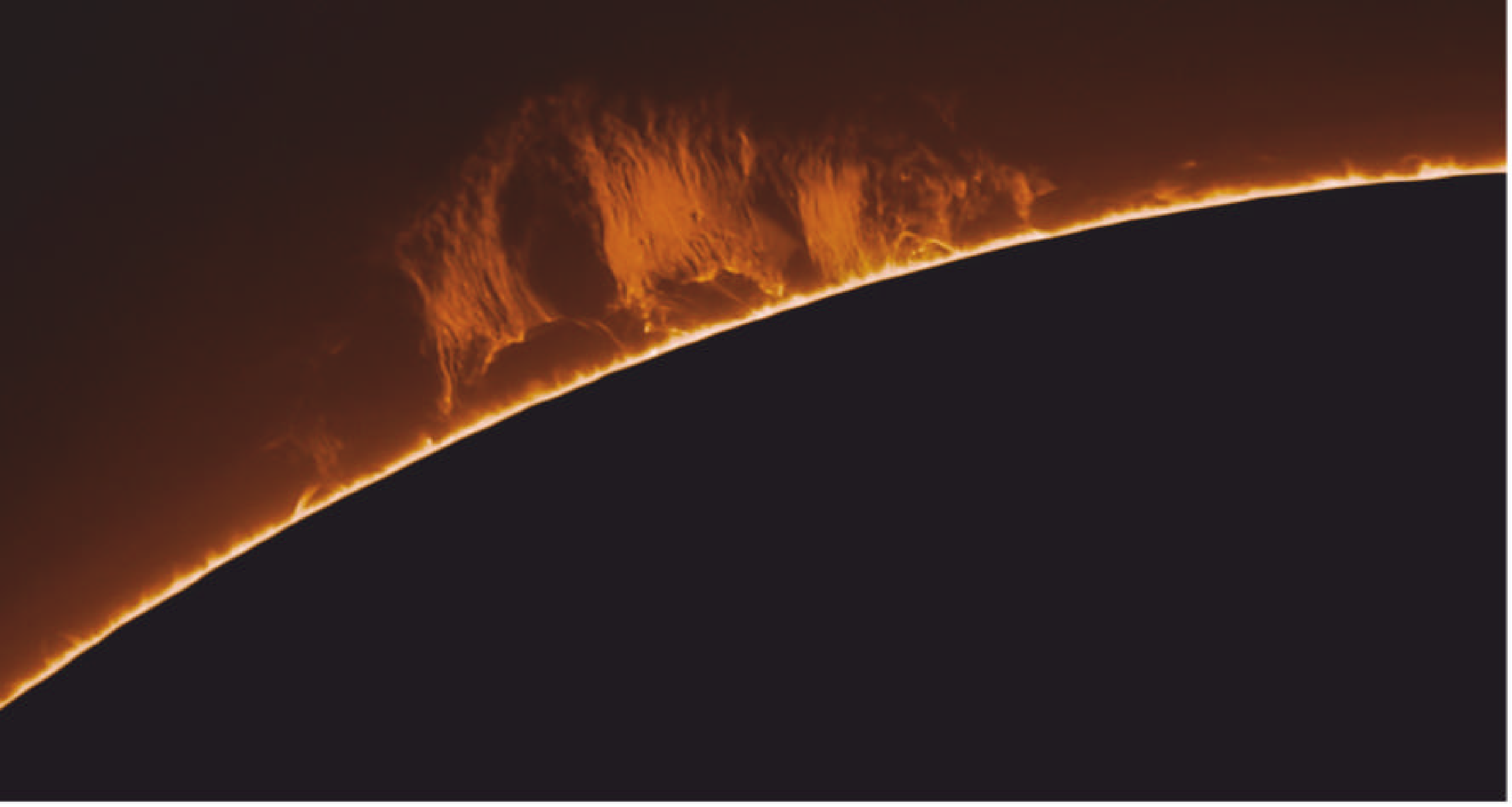
Edge of the Moon

The author captured this white-light image of the Sun during the 2017 Great American Eclipse, revealing a striking silhouette of the Moon's limb. PHIL HARRINGTON

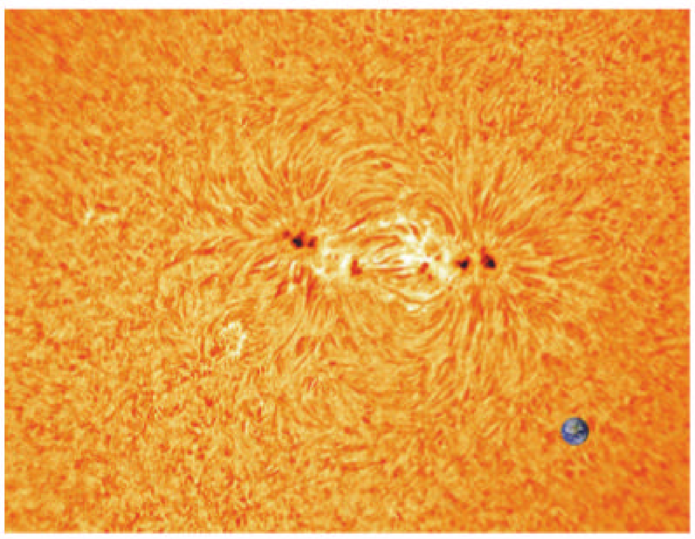
AS THE MOON SLOWLY ENCROACHES on the Sun during an eclipse, use a white-light filter and carefully view the edge of the Moon at 100x power or more. You will immediately notice its craggy profile, much like a sawtooth. Those are the many hills, valleys, and craters that lie just at the brink of visibility bordering between the near side and the far side of our satellite. Watch as those lunar "teeth" cut across the Sun's disk, cleaving through sunspot groups visible at the time. If you happen to have access to a detailed map of the Moon's exact orientation at the time of the eclipse, also try to identify which lunar features are silhouetted. One source of such maps is the Virtual Moon Atlas, which is free to download from https://ap-i.net/avl/en/start. *—P.H.*

Hydrogen-alpha filters and scopes

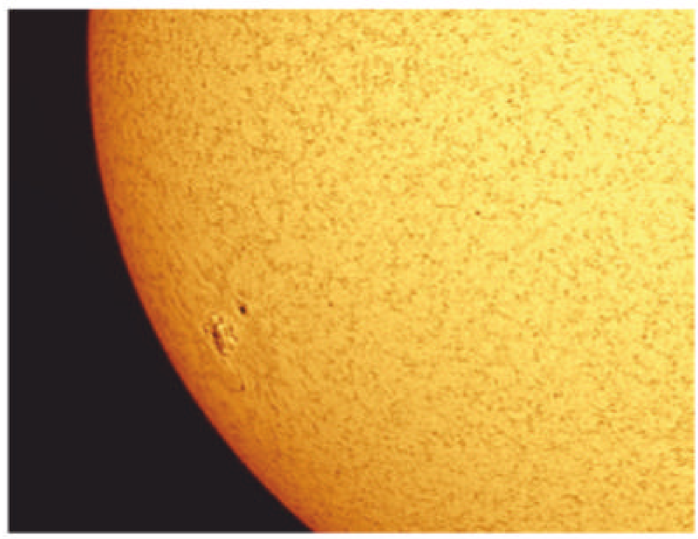
Back in the day, viewing the Sun through a special Hα filter was something exotic, available only to institutions and wealthy amateurs. Over time, however, their prices have dropped, and they are now surprisingly affordable. Brands including Coronado (www.meade.com/solar/solar-scopes.html), DayStar (farpointastro.com/products/solar-viewing) and Lunt (luntsolarsystems.com) sell



Massive amounts of solar gas and plasma are blasted high above the surface when the Sun's complex web of magnetic field lines violently interact, creating arced prominences like those seen here. JEFF PADELL



Sunspot 2645 is seen here in Hα on April 1, 2017, through the Kitt Peak National Observatory Visitor Center Telescope. Earth is superimposed on the image for scale. RON COTTREL



Sunspot AR2781 popped up during Solar Cycle #25. In this Hα shot from November 4, 2020, the sunspot is swinging around the Sun's eastern limb. JOHN CHUMACK

Hα filters for amateur instruments, as well as dedicated Hα telescopes.

That's fortunate, since this wavelength is where the action is. Even when the Sun appears barren through white-light filters, Hα filters give us a ringside view of the Sun's magnificent chromosphere, the layer directly above the photosphere. Like sunspots, Hα features come and go depending on solar activity.

The most spectacular Hα features are prominences, flamelike protrusions that gracefully reach out from the solar limb. Even the smallest of these prominences would tower over our entire planet. Some extend from the edge of the solar limb like a grove of trees along a distant horizon. Others hook and loop away from the disk, forming giant arcs. When observing the Sun, keep tabs on these features throughout the day and you will see that their structures can dramatically evolve.

If a prominence appears along the trailing edge of the Sun, solar rotation can carry it onto and across the disk. As a prominence moves across the face of the Sun, it appears dark thanks to its contrast against the brighter chromosphere. This creates what looks like a shadowy solar serpent known as a filament.

Also keep an eye out for bright patches across the photosphere called plages, which occur where a magnetic disturbance has broken through the photosphere. Plages often coincide with sunspot groups, although they may also appear alone.

The most dramatic and rarest Hα events, however, are solar flares. These sudden, violent eruptions occur in and around sunspot groups, resembling rivers of white-hot lava flowing between the spots. Flares usually last between five and 10 minutes, although some may last for several hours. Despite their brief existence, individual solar flares release enough energy to power the United States for roughly 100,000 years. They also release a flood of charged particles, and if the aim is just right, these particles will be drawn to Earth's two magnetic poles. As they collide with our upper atmosphere, the air molecules glow, creating the beautiful aurora known as the northern and southern lights.

Finally, while all these Hα solar features come and go, spicules are always visible. These jets of plasma jut upward from the chromosphere all around the edge of the solar disk. At lower magnifications, they're reminiscent of peach fuzz. But increasing to 150x power or more will resolve individual spicules, which allows you to watch them change before your eyes.

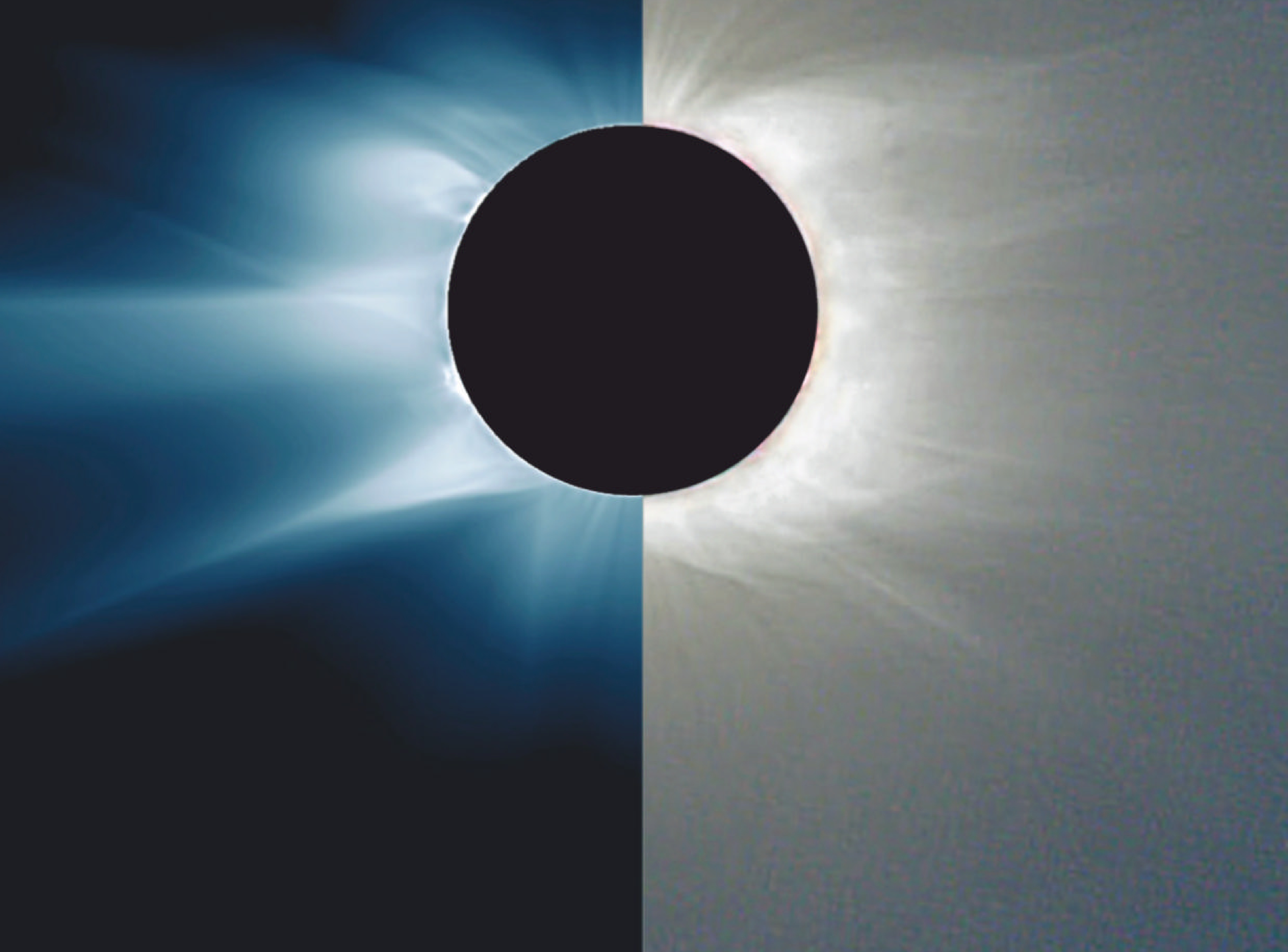
If viewing all these amazing solar features interests you, make sure to pay extra attention to your Hα filter's bandwidth — the range of light frequencies that can pass through the filter largely unimpeded. A bandwidth of 3 to 4 angstroms (Å) will reveal prominences, but you will need a filter with a bandwidth no more than 1 Å to spot features like filaments.

Two terrific sources for the latest news on solar activity are https://spaceweather.com and http://halpha.nso.edu. Both show real-time images of the Sun, the former in white light and the latter in Hα. Be sure to bookmark them.

A stellar lineup of varied solar sights awaits us every sunny day. So, make sure to take some time and explore our wondrous host star; you'll quickly become a Sun-worshipper. Just don't forget your sunblock.

Phil Harrington *is a longtime contributor to* Astronomy *and the author of many books. He has also observed the Sun for decades.*

Revealing the 2020 ECLIPSE

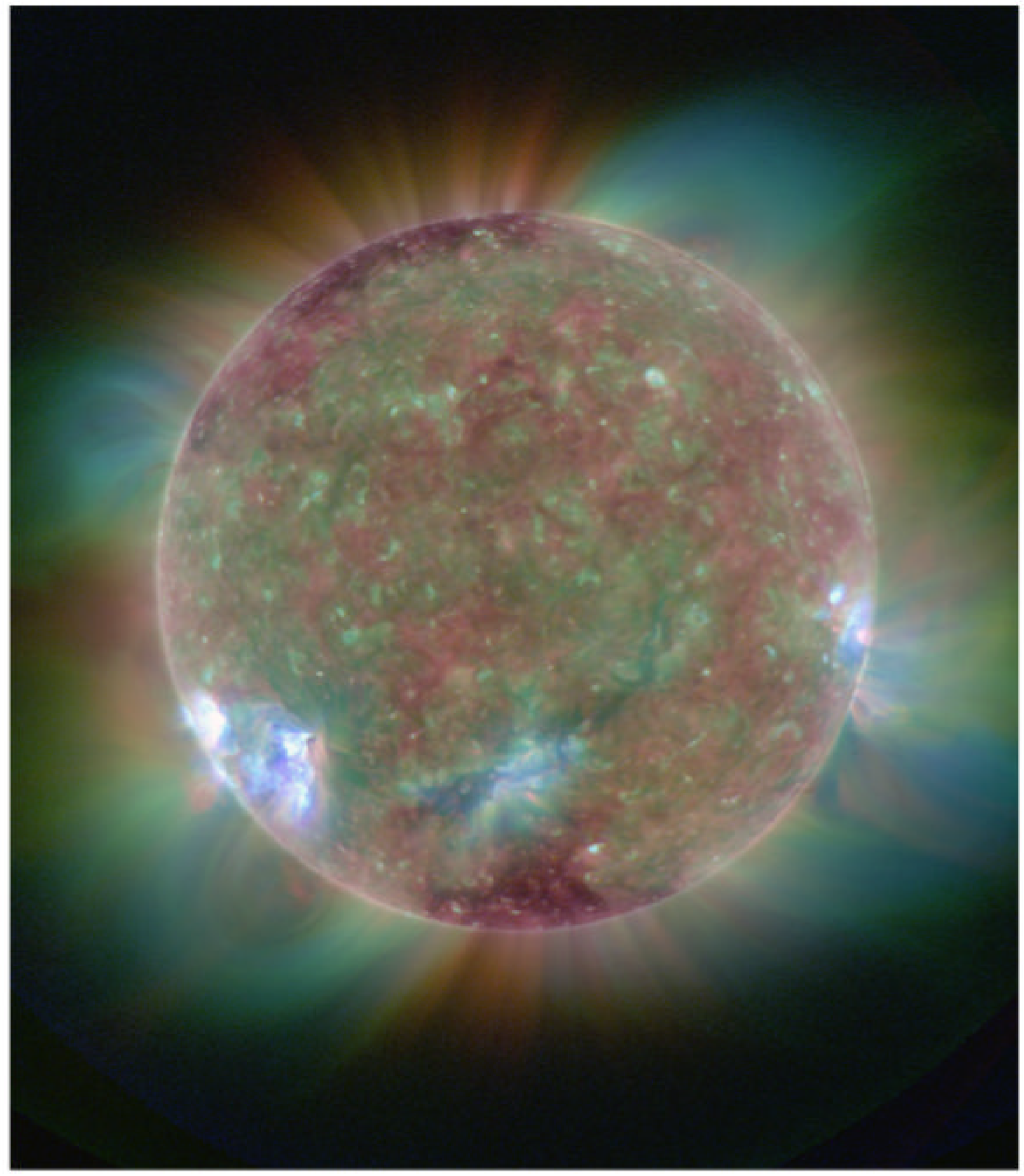


Though most were unable to see last year's total solar eclipse in person, local astronomers and websites captured the cosmic event. **BY JAY M. PASACHOFF**

Anyone who has had the pleasure of viewing a total solar eclipse understands the desire to see another. This makes it easy to fall down the eclipse-chasing rabbit hole. But witnessing cosmic wonder isn't the only draw when you're an eclipse seeker.

Solar eclipses give astronomers a unique opportunity to view objects around the Sun, such as Mercury and nearby stars normally blocked by the Sun's brilliance.

In western Chile, Professor Patricio Rojo went to Gorbea with his wife and children. He captured some interesting views of the corona though the clouds using the 400mm telephoto we had gifted him. PATRICIO ROJO



The National Oceanic and Atmospheric Administration's GOES-16 spacecraft captured this false-color image of the Sun in extreme ultraviolet light — wavelengths shorter than visible light — at eclipse time with its Sun-facing Solar Ultraviolet Imager. The satellite's main cameras face Earth and continuously provide images of terrain and clouds from its geosynchronous vantage point. NOAA/GOES-16, COURTESY OF DANIEL B. SEATON/U COLORADO & NOAA

But it isn't just the objects around the Sun that draw astronomers to view eclipses. Scientists still don't agree how the Sun's corona, the outermost atmosphere of our star, is heated to more than a million degrees Fahrenheit (555,500 degrees Celsius), while the Sun's surface is only 9,940 F (5,500 C). The longest possible duration of an eclipse is 7 minutes 31 seconds, but most are considerably shorter, and total eclipses occur about once every 18 months. So, research opportunities during totality are sporadic at best and astronomers devote months or years of planning to take advantage of those few precious minutes.

Unlike totality during the July 2, 2019, eclipse — which was visible low in the sky along a narrow path through Chile and Argentina shortly before sunset — the December 14, 2020, total eclipse was high in the sky over the Patagonia region in South America.

But that wasn't the only major difference between the two eclipses. Planning for the December 2020 total solar eclipse was especially sporadic due to fluctuating travel restrictions related to the COVID-19 pandemic. My scientific team's original plans involved accompanying a tour group to a viewing site in Argentina, but restrictions led the cancellation of most tours, including our own. However, my team still managed to obtain permission to enter Chile and view from the otherwise-closed Villarrica National Park.

FAST FACT

The longest possible duration of an eclipse is 7 minutes 31 seconds, but most are considerably shorter.

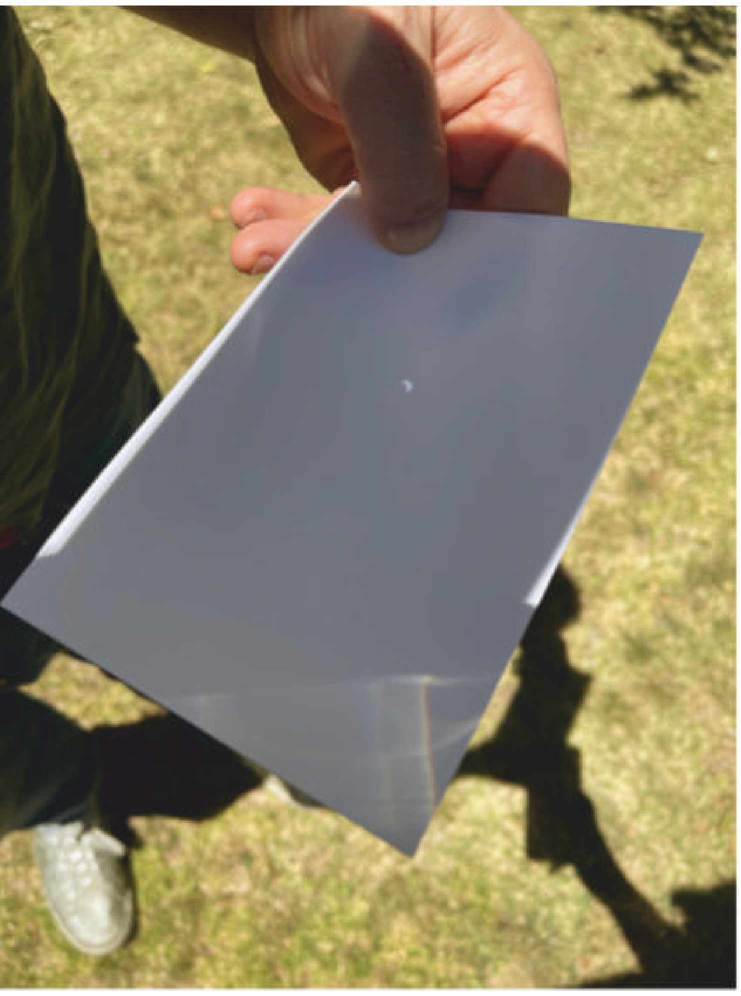
As eclipse day approached, I was hopeful that COVID would retreat, making it safer to navigate through airports to our restricted-access site for viewing the eclipse. Instrument specialists Alan Sliski of Lincoln, Massachusetts, and David Sliski of the University of Pennsylvania planned to join me as well.

A week before the eclipse, I decided to cancel my trip because of the increase in COVID-19 cases. Though I've already seen 35 totalities, it was a difficult decision to make. Instead, I took in the views from behind a computer screen miles away. Thankfully, local amateur and professional astronomers were able to share the experience with the world and give us scientific data to study.

Capturing an eclipse

Leading up to the eclipse, a research group from Predictive Science Inc. continued their streak of predicting what

PREVIOUS PAGE, FROM LEFT: PREDICTIVE SCIENCE INC.; JAY PASACHOFF, ANDREAS MÖLLER, PATRICIO ROJO, VERÓNICA ESPINO, ET AL./WILLIAMS COLLEGE EXPEDITION (CHRISTIAN LOCKWOOD, DAVID SLISKI, ALAN SLISKI, THEO BORIS, XAVIER JUBIER, THIERRY LEGAULT)/NSF AGS/COMPUTER COMPOSITE BY WENDY CARLOS WITH IMAGES FROM CHILE AND ARGENTINA



Elizabeth Isaman, our contact at the American Embassy in Santiago, helped us gain permission to enter Chile despite travel restrictions. She had clear weather to view the partial phases as seen from Santiago. ELIZABETH ISAMAN

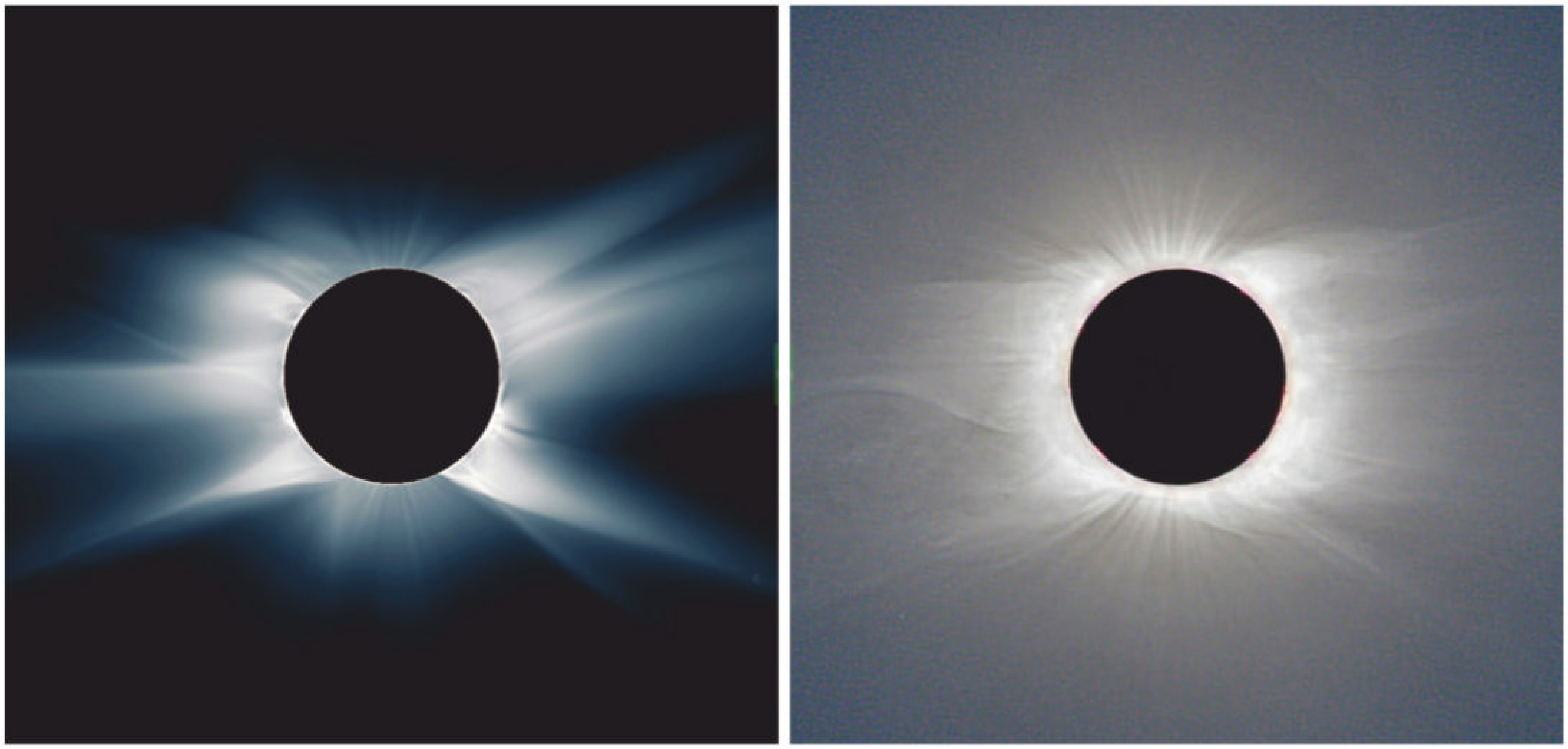
Verónica Espino captured these prominences near Las Grutas, Argentina. VERÓNICA ESPINO

Our team's meteorological station, set up and ready to go. JAY RACELA AND MARCOS PEÑALOZA-MURILLO (WILLIAMS COLLEGE)

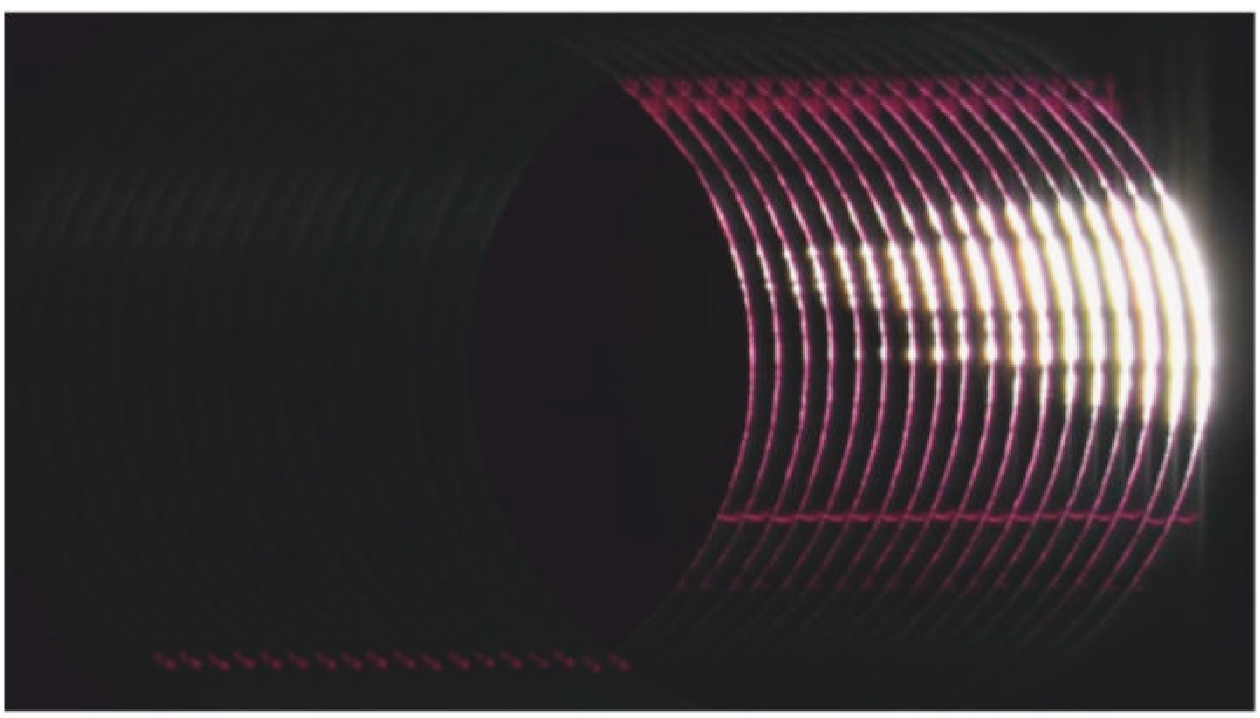
This image shows the predicted appearance of the eclipse at totality, based on observations from NASA's Solar Dynamics Observatory. PREDICTIVE SCIENCE INC.

the Sun's corona would look like. These computations were based on observations from NASA's Solar Dynamics Observatory of the solar magnetic field in the months leading up to the eclipse. Because the Sun's activity cycles from low to high and back to low about every 11 years, and the latest cycle began at the end of 2019, the researchers predicted that observers would see increased activity, such as forked streamers near the equator on either side of the Sun as well as plumes emanating from the poles. After the eclipse, some of the earliest images we received showed such prominences arcing up from the surface of the Sun.

The members of my team who had made the trip were forced to improvise when their views turned cloudy. Instead of capturing a view from Villarrica, they traveled east to the border with Argentina in an attempt to catch a glimpse of the event. The clouds remained, however, and due to



This set of images compares the predicted appearance of the eclipse (left) with its actual appearance (right). LEFT: PREDICTIVE SCIENCE INC.. RIGHT: JAY PASACHOFF, ANDREAS MÖLLER, PATRICIO ROJO, VERÓNICA ESPINO, ET AL./WILLIAMS COLLEGE EXPEDITION (CHRISTIAN LOCKWOOD, DAVID SLISKI, ALAN SLISKI, THEO BORIS, XAVIER JUBIER, THIERRY LEGAULT)/NSF AGS/COMPUTER COMPOSITE BY WENDY CARLOS WITH IMAGES FROM CHILE AND ARGENTINA



This progression shows the evolution of Baily's beads as totality begins. ANDRÉS VATTUONE

COVID-19 restrictions, they were unable to cross into Argentina to find a new observing site. Instead, the team returned to the hotel and crewed a meteorological station in partnership with Marcos Peñaloza-Murillo of the Universidad de los Andes in Mérida, Venezuela. Using these measurements, we are now studying the effect of the abrupt eclipse darkening on terrestrial atmospheric parameters and potential gravity waves emanating from the path of totality. The equipment measured: temperatures at three heights, the pressure, the wind speed, and the amount of solar energy reaching a given area of Earth's surface every 20 seconds throughout the duration of the eclipse. We had already collected comparison data from the days before and took more in the days following.

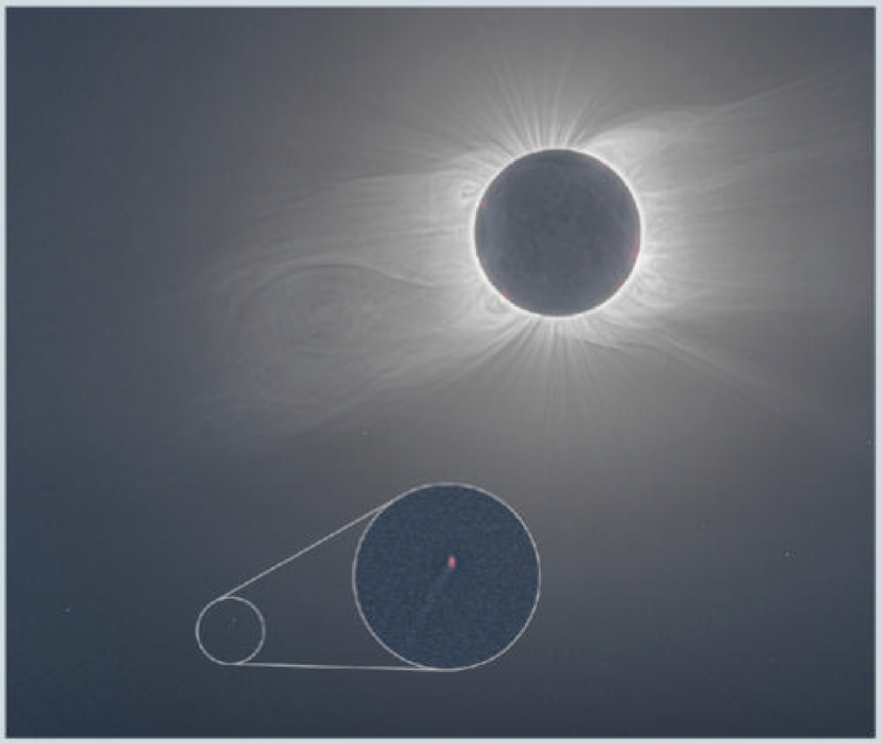
Filmmakers Matthew and Michelle Taylor accompanied my team in the hopes of capturing Baily's beads at the beginning and end of totality. Unfortunately, the cloudy skies made it impossible to get a clear enough image of the eclipse to do so.

The first notification I received of coronal observations through reasonably clear skies came from Andreas Möller of Germany, who had gone to Argentina with the U.K. Astro-Trails tour — one of the few tours that had not been canceled — to a site at Piedra del Águila. Back in New York City, my longtime colleague, computer-adept composer Wendy Carlos, created a composite of Möller's images by choosing the best exposed part of each. She sent the result to Joy Ng and Lina Tran of NASA's Goddard Space Flight Center, who compared the photos with predictions generated by Predictive Science Inc. The resulting press release not only shows a fade from their prediction to our actual image of the event, but also provides a slider that allows readers to compare the two images in detail.

Eclipse enthusiasts John Beattie and Tim Todd chartered two Cessna Citations to carry 11 eclipse observers from La Araucanía International Airport to 33,000 feet (10,058 meters) above the Pacific before the eclipse reached South America. Michael Gill, who runs the Solar Eclipse Mailing List, and Patrick Poitevin, who ran the first Solar Eclipse Conferences, were among those on board the second plane, along with Beattie, Craig Small, Jordan Sutton, and Ken Schwartz.

Looking forward

What's next? We have plenty of observations to keep us busy, but that doesn't



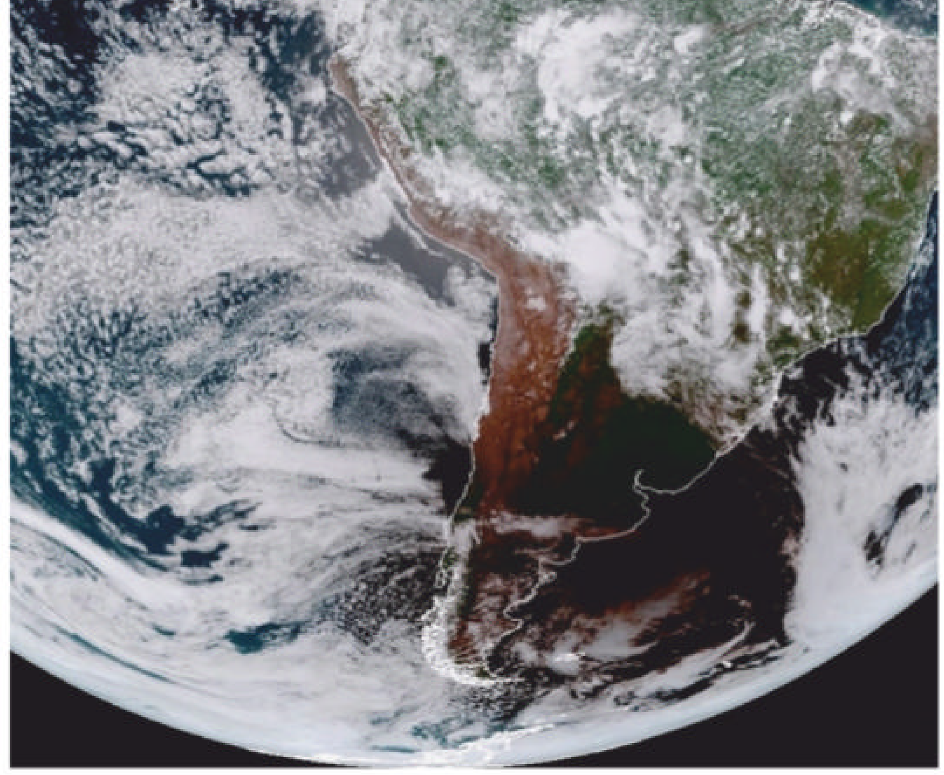
This composite image combines 65 frames and shows Comet C/2020 X3 (SOHO) during the eclipse. ANDREAS MÖLLER, PROCESSED BY JAY PASACHOFF AND ROMAN VANUR

COMET LIGHT, COMET BRIGHT

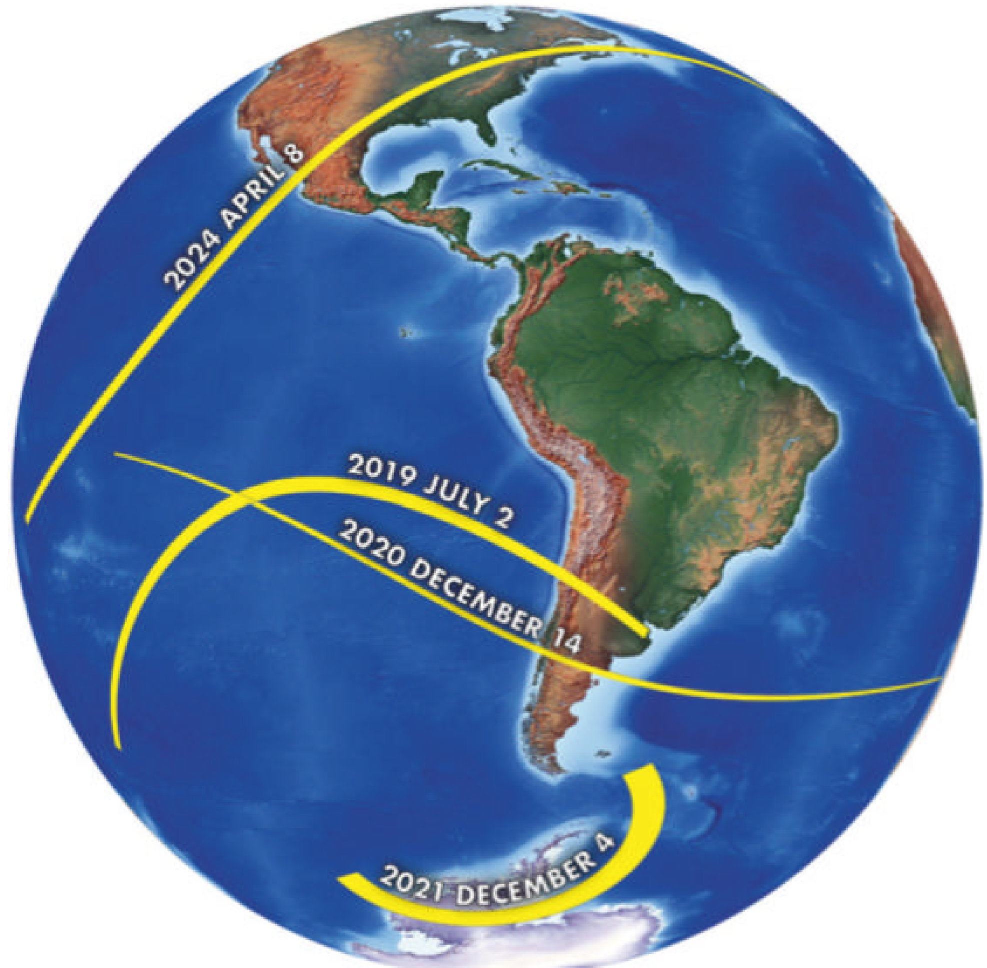
Looking through satellite data from the NASA-funded citizen science Sungrazer Project, Thai amateur astronomer Worachate Boonplod spotted a new comet speeding by the Sun on December 13, a day before the eclipse. Sungrazer encourages citizens scientists to scour images from the joint European Space Agency and NASA Solar and Heliospheric Observatory (SOHO) to find new comets. Astronomers were eager to see if the little speck would be visible in eclipse photographs.

Hopeful it would appear in ground-based observations, I sent a full set of Andreas Möller's raw eclipse images to my colleagues Vojtech Rusin and Roman Vanur in Slovakia. Lo and behold, Vanur's resulting composite, made from five dozen of Möller's images, indeed shows the comet.

Considering about 2,000 SOHO comets are still unnumbered, I reached out to the U.S. Naval Research Laboratory, encouraging them to number this new comet. It soon became SOHO–4108. Later, the International Astronomical Union Minor Planet Center at the Smithsonian Astrophysical Observatory released the comet's new name — C/2020 X3 (SOHO). Additional observations showed it to be a Kreutz sungrazer, a family of comets stemming from a parent comet that broke up well over a thousand years ago. — *J.P.*



ABOVE: The GOES-16 spacecraft captured the path of totality across Patagonia. BELOW: Past and future eclipse paths and dates are mapped on the globe. ABOVE: TIM J. SCHMIT, NOAA/NESDIS CENTER FOR SATELLITE APPLICATIONS AND RESEARCH (STAR). BELOW: MICHAEL ZEILER, GREATAMERICANECLIPSE.COM



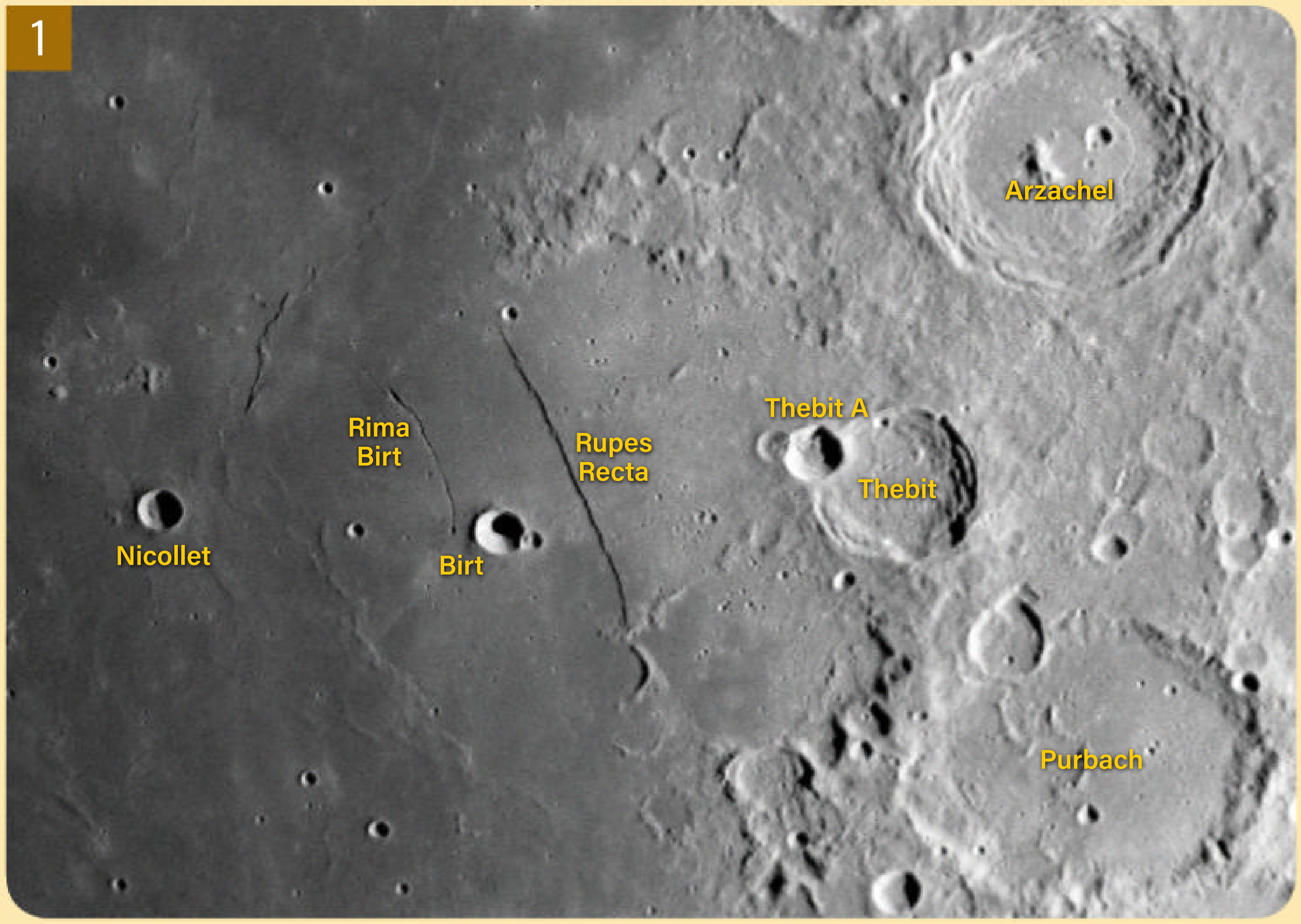
mean we aren't already planning to collect more in the future, as the Sun continues through its sunspot cycle. This year's annular eclipse over Canada, northwestern Greenland, the North Pole, and Siberia on June 10, 2021, will have partial phases visible in the northeastern U.S. Unfortunately the same can't be said for the Antarctica eclipse on December 4, 2021. Predictions made by Jay Anderson at http://eclipsophile.com indicate clouds will impact the viewing.

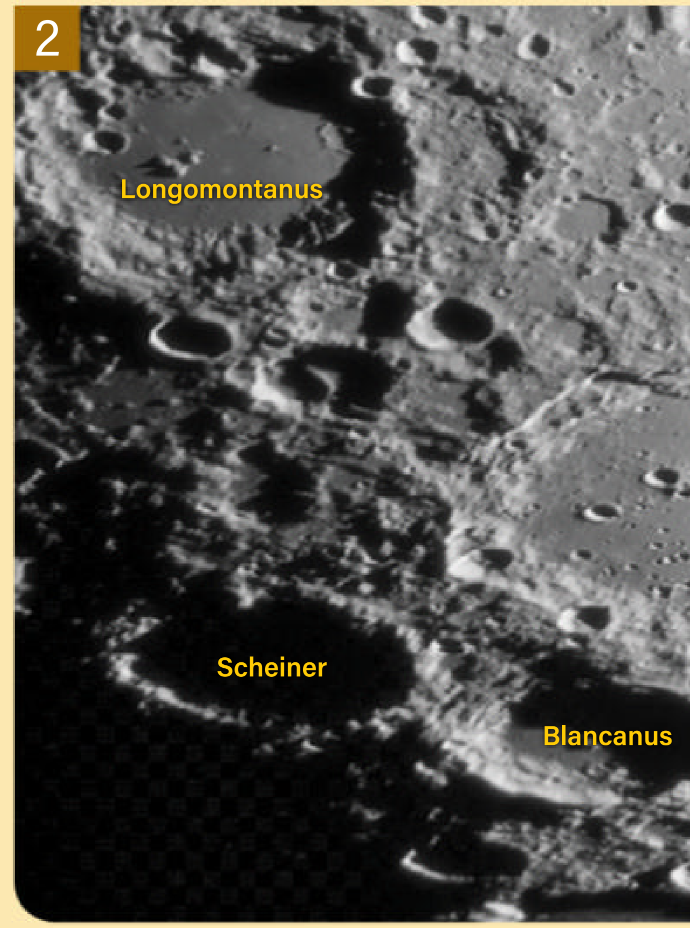
With neither a total solar eclipse nor an annular eclipse, 2022 will be an unusual year. So, eclipsophiles are preparing plans for the "hybrid" annular/total eclipse that will clip a peninsula at the extreme western end of Australia in 2023 before going on to East Timor and western Papua. The October 14, 2023, annular eclipse that crosses the U.S., Mexico, Central, and South America will also have partial phases visible throughout the U.S.

But those annular eclipses are child's play compared to what's coming in 2024: The next Great American Eclipse. Totality during this much-anticipated event will cross from Mexico through Texas and on through the upper Midwest to northern New England and the Canadian Maritimes. And, if one can bear to wait a few more decades, the May 1, 2079, total solar eclipse will cross over both New York and Boston.

Regardless of which eclipse you may see, you certainly won't be disappointed — whether you're an astronomer or simply an eclipse enthusiast.

Jay Pasachoff *is a professor of astronomy at Williams College and a veteran of 35 total solar eclipses. His research is sponsored by the National Science Foundation's Division of Atmospheric and Geospace Sciences.*





LEFT: NASA/GSFC/ASU

Easy Moon observing

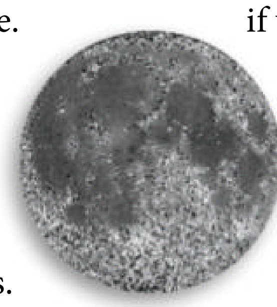
Here's a strategy that will help you enjoy our closest celestial neighbor. BY MICHAEL E. BAKICH

IF YOU LIVE IN or near a large, well-lit city, or own only a small telescope, your observing choices are limited. One object that won't disappoint you, however, is the Moon. Following it telescopically through a lunar month can be fascinating. But keep in mind that, as opposed to every other celestial body, the brightest Moon is the worst time to view it. That's because the Sun is shining on the Moon from directly behind us, which shrinks shadows and hides details.

Two intervals during the lunar "month" (from one New Moon to the next) are best for observers. The first begins shortly after New Moon and continues until two days past First Quarter. Amateur astronomers tend to favor this span because the Moon lies in the evening sky. An equally good observing period starts about two days before Last Quarter and goes until the Moon lies so close to the Sun that it's lost in morning twilight. During each of these spans, shadows are longer and features stand out in sharp relief. One benefit you'll get if you observe the Last Quarter Moon is that the atmosphere before dawn is steadier than after sunset, when a lot of heat remains in the atmosphere.

Michael E. Bakich *is a contributing editor of* Astronomy.

Strategy

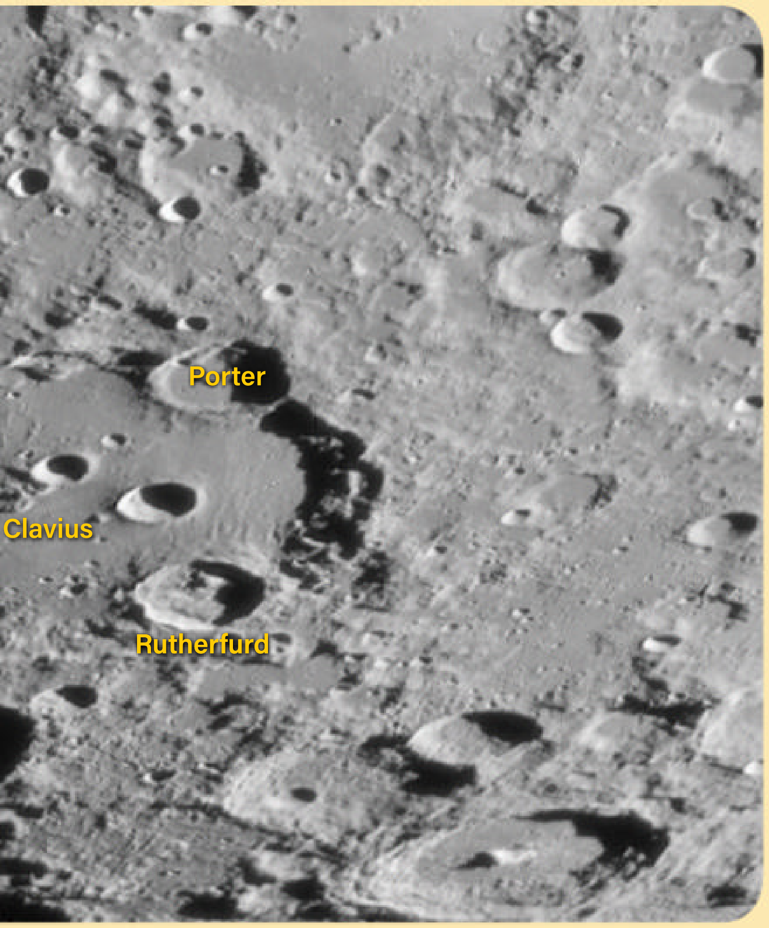


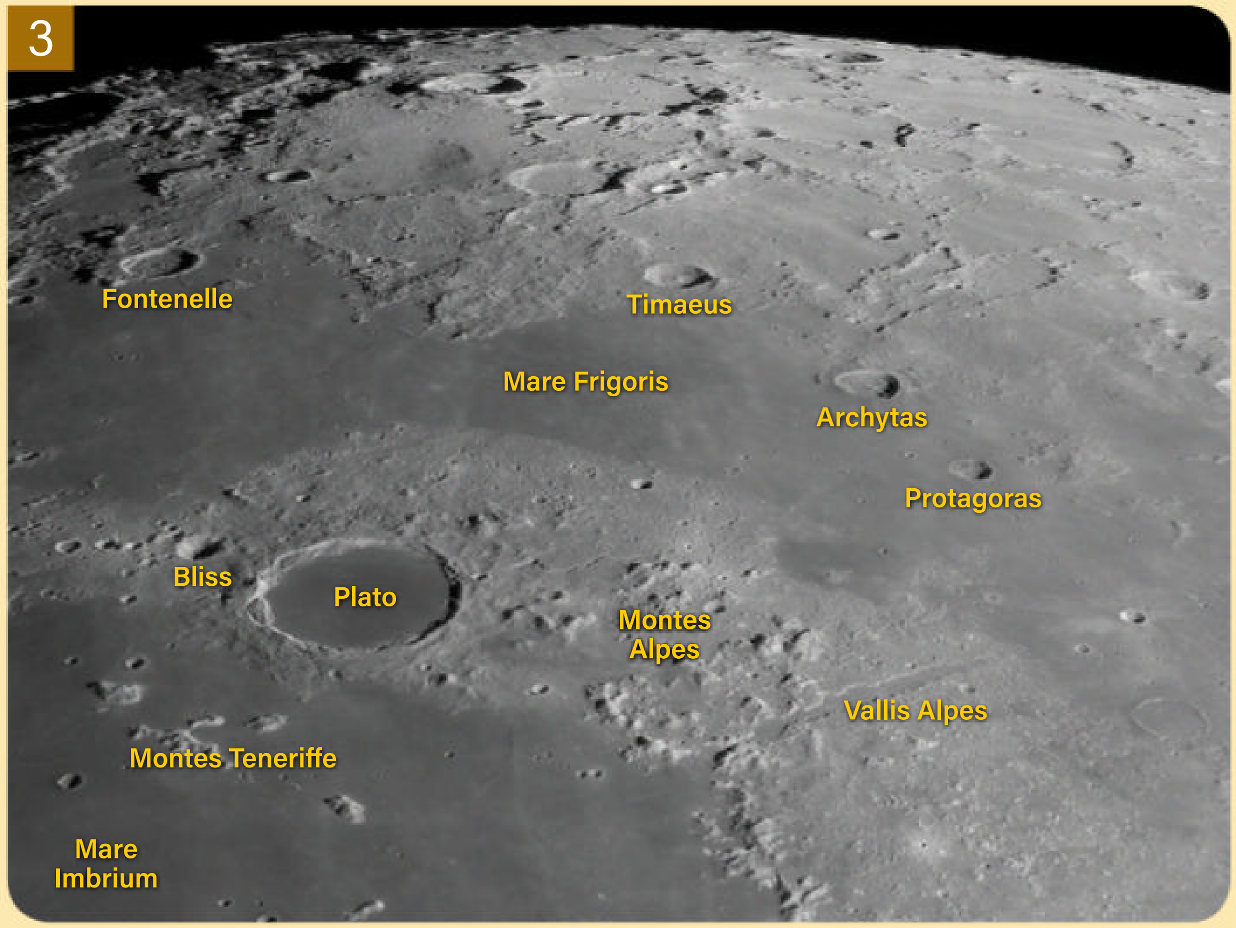
The best places to point your telescope lie along the terminator, the line that divides the Moon's light and dark portions. Here you can spot the tops of mountains protruding just high enough to catch sunlight, while the surrounding lower terrain remains in shadow. On large crater floors, you can follow "wall shadows" cast by the towering sides of those craters. Features along the terminator change in real time and, during a night's observing, the differences you'll see through your telescope are striking. Observing on successive nights makes it easier to follow the terminator's progress.

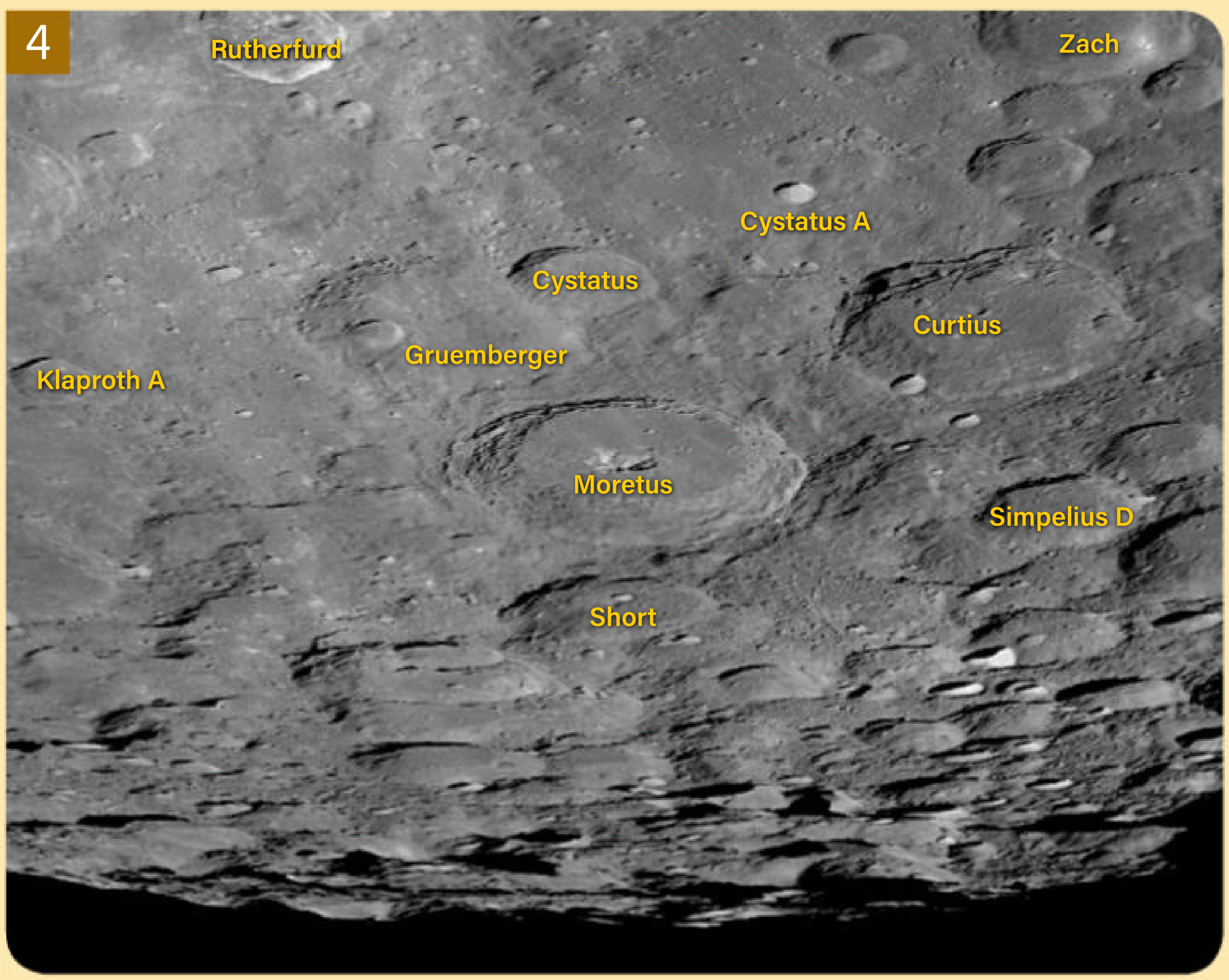
By far the greatest percentage of lunar features are craters. Craters range in size, so challenge yourself by finding the smallest crater you can see. Or see how many small craters (called craterlets) in a given area you can observe. For example, if you look at the floor of Plato Crater, a medium-size scope will reveal four craterlets, each about 1¼ miles (2 kilometers) across.

By the way, any quality telescope — of any type — will reveal lots of lunar details. Whether you own a 3-inch refractor, a 6-inch reflector, or a 14-inch SCT, you'll see a lot. Observers without a permanent observatory usually pick a scope they can set up many nights in a row.

Because the Moon is so brilliant, especially through a telescope, observers often use a neutral density filter to reduce its light. Such an accessory is great because it doesn't change anything else about the view.







1. Arzachel Crater makes a great starting point. Examine how different parts of its wall appear. The prime target in this region, however, is Rupes Recta, also known as the Straight Wall. You'll see it best when it's in sunlight with the terminator nearby. Then identify Thebit Crater and Thebit A, Birt Crater, and Nicollet. Finally, try to find Rima Birt, a less prominent version of Rupes Recta. BRIAN FORD

2. Clavius Crater also is a great target for beginning lunar observers. Inside, it features a curving line of half a dozen craterlets of shrinking size. Porter Crater and Rutherfurd Crater sit on its edge. Other significant craters nearby are Blancanus, Scheiner, and Longomontanus. JAMES EDLIN

3. Plato Crater is one of the most striking features on the Moon, so it makes an ideal location to begin. The mountains to its lower right are the Montes Alpes. Interesting though they are, the top target here is Vallis Alpes, a 100-mile-long (162 km), lava-filled chasm. Take your time identifying the many other craters in this region. CHRIS SCHUR

4. Moretus Crater, with its central mountain, lies near the bottom of the Moon as we see it, in what are called the Southern Highlands. Many craters pack into this region, so take your time identifying them. DAMIAN PEACH

Moon watchers use two other ways to cut the Moon's brightness. Boosting the magnification reduces the field of view so less light gets through. New observers, however, may find identifying features in such tiny areas difficult. The other way is to use an aperture mask — a round piece of cardboard with a hole cut out. It covers the front of your telescope so less light gets through, but doesn't limit the field of view.

Where to start

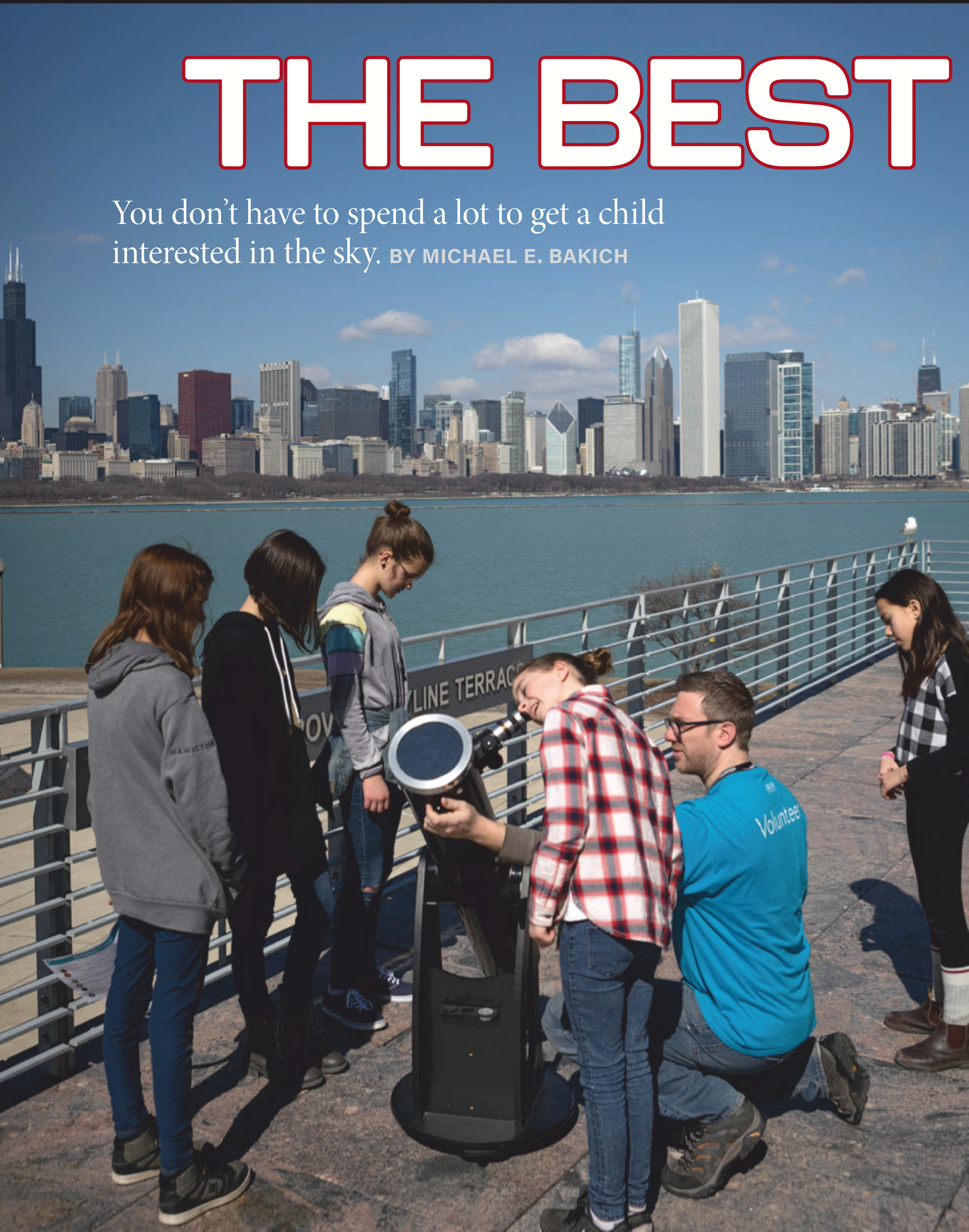
One of the best ways to learn the Moon is to have a lunar map or globe with labeled features next to your telescope while you observe. Start by finding a prominent crater that's currently visible and work outward from it. You'll quickly learn how your telescope's field of view differs from your reference. Some scopes flip the image; others rotate it 180°. Yours may do both.

You'll find one great choice for a Moon globe at MyScienceShop.com. This 12-inch diameter globe, based on images supplied by the Lunar Reconnaissance Orbiter (launched in 2009 and still orbiting the Moon), has 1,473 features labeled.

When you do head out, get comfortable (I love sitting in a chair), take your time, and have fun.

THE BEST

You don't have to spend a lot to get a child interested in the sky. BY MICHAEL E. BAKICH



SCOPES for kids

MY INTEREST IN ASTRONOMY began in third grade, when my parents bought me a set of constellation flash cards. We couldn't afford a telescope, but I was able to borrow a neighbor's small refractor from time to time, and whenever I could get my hands on it, I would spend hours exploring the night sky.

Back in the '60s, the Milky Way and its many wonders were easy to spot from my backyard even though I lived in a small city. In high school, I joined an amateur astronomy club and viewed through a borrowed 10-inch reflector many times. It wasn't until I was graduated from college that I finally owned my own scope. But my case is unusual — most amateur astronomers I know owned their own small telescope when they were young.

I can't say that buying your child a telescope will make them an amateur astronomer. But even if it doesn't, it will help ignite a spark of curiosity that may bloom into a science-loving flame. And who knows where that will lead?

Baby steps

When you set up your child's scope, be prepared, as excited kids will touch anything new and might even grab the scope to help steady themselves. Fortunately, all the scopes I list here can take mild handling. And once you've bought a scope, remember it's their telescope. The best thing you can do is stand back and let them explore the night sky.

One thing I've learned during my years in the planetarium field is that when you're at the scope with a child, go easy on the numbers. It may fascinate you that Jupiter is large enough to hold 1,300 Earths and is only one-thousandth the size of the Sun, but numbers like that can quickly overwhelm a child. It is important to get the facts straight, but don't lose sight of the ultimate objective. You're not trying to

COURTESY OF THE ADLER PLANETARIUM

CELESTRON FIRSTSCOPE

The FirstScope is an inexpensive way to foster a child's love of astronomy. This 3-inch reflector is attached to a small Dobsonian mount. To observe with it, simply place the telescope on a table and move the tube in the direction of the target. Do note that the quality (in this case, steadiness) of the view will depend on how sturdy the table is. A shaky table will make viewing nearly impossible. One solution might be a platform made from two or three concrete blocks, whose height is determined by the child's height. The FirstScope also is quite small, making it an ideal companion for an outdoor adventure.

SPECIFICATIONS
Optical design: Newtonian reflector
Mount: Dobsonian
Aperture: 3 inches (76 mm)
Focal length: 300mm
Focal ratio: f/3.95
Eyepieces: 20mm (15x) and 4mm (75x)
Weight: 4.3 pounds (1.95 kg)

COURTESY OF CELESTRON

COURTESY OF CELESTRON

CELESTRON EXPLORASCOPE 70AZ

The Explorascope 70AZ is a 2¾-inch refractor on a simple alt-azimuth mount. With its 700-millimeter focal length, this telescope delivers higher magnification than the other models listed here. It also features a slow-motion control rod, which lets the user guide the scope without grabbing the tube. The scope comes with two eyepieces, a 3x Barlow lens, a 90° erect-image diagonal (for viewing terrestrial objects "right-side up"), a finder scope, and an accessory tray.

SPECIFICATIONS
Optical design: Refractor
Mount: Alt-azimuth
Aperture: 2.76 inches (70 mm)
Focal length: 700mm
Focal ratio: f/10
Eyepieces: 20mm (35x) and 4mm (175x)
Weight: 6.1 pounds (2.8 kg)

CELESTRON INSPIRE 100AZ REFRACTOR

The Inspire 100AZ is a 3.9-inch refractor, the second-largest telescope in this list. The unit sits atop a tripod with 1¼"-diameter steel legs and requires no tools to set up. Like Celestron's 70AZ, the 100AZ has a slow-motion control rod that allows the user to aim the scope without grabbing the tube. The scope comes with two eyepieces, an erect-image star diagonal, a red LED flashlight, a red dot finder scope, an integrated smartphone adapter, and an accessory tray.

SPECIFICATIONS

Optical design: Refractor
Mount: Alt-azimuth
Aperture: 3.93 inches (100 mm)
Focal length: 660mm
Focal ratio: f/6.5
Eyepieces: 20mm (33x) and 10mm (66x)
Weight: 13.4 pounds (6.1 kg)

COURTESY OF CELESTRON

COURTESY OF EXPLORE SCIENTIFIC

EXPLORE SCIENTIFIC FIRSTLIGHT 90MM

The FirstLight 90mm, which also goes by the company's designation FL-AR90500AZ, is a 3½-inch refractor. It sits on a yoke mount and incorporates a rod to move the scope without touching the tube. The unit sits atop an aluminum tripod. Explore includes two eyepieces, an erect-image star diagonal, a red dot finder scope, a smartphone camera adapter, and an accessory tray.

SPECIFICATIONS

Optical design: Refractor
Mount: Alt-azimuth
Aperture: 3.54 inches (90 mm)
Focal length: 500mm
Focal ratio: f/5.5
Eyepieces: 20mm (25x) and 9mm (56x)
Weight: 5 pounds (2.27 kg)

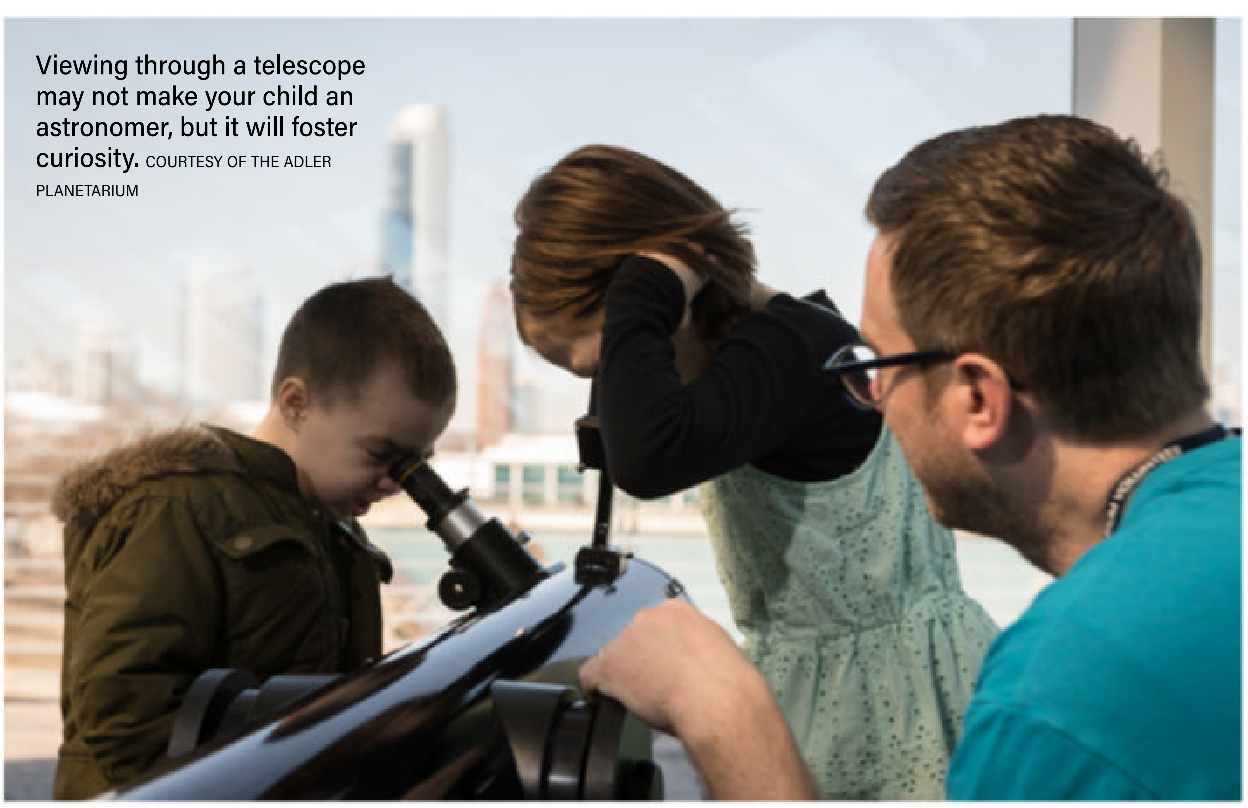
give them a total grasp of astronomy; rather, you're trying to excite their imagination and get them interested. Questions will come, and you can answer those in as much detail as you perceive your child can handle. If they want more, be prepared to hand them a book (or a copy of *Astronomy* magazine), or suggest an age-appropriate website.

What to look at

As amateur astronomers, we love to test ourselves: "What's the faintest object I can see tonight?" "How many craterlets can I count in Clavius Crater?" "Does that 11th-magnitude galaxy have two or three arms?" When you're showing a child the sky, however, it's the bright stuff that matters. And that means the Moon. Start with an eyepiece whose field of view will show our whole satellite. (Since the Moon is so brilliant, you may want to invest in a neutral density filter or create an aperture mask).

Ask your child what's most interesting to them. Then, increase the magnification to zoom in on that area. Go back the next clear night and explain why the Moon looks different. Most important, let your child decide how long each observing session lasts.

Staying in the solar system, Saturn and Jupiter can't be beat. Through a small scope, however, Saturn's rings will



Viewing through a telescope may not make your child an astronomer, but it will foster curiosity. COURTESY OF THE ADLER PLANETARIUM

be tiny. You can increase the magnification, but that will reduce the time the planet remains in view. Luckily, kids' eyes are much better than those of most adults, so your child will see more detail than you do.

Jupiter's belts will show up well, but you might want to concentrate on the four Galilean moons. From night to night, their changing positions (and the arrangements they make) are fascinating. Unfortunately, Mars, even when it's closest to Earth, can be a bit of a letdown for new observers, as few details can be distinguished. But a quick glance could be used as an opportunity to build your child's interest in space exploration.

When you progress to deep-sky objects, you really have to be careful. Through small scopes, not many are worthy targets. Avoid galaxies and instead concentrate on open clusters, a few nebulae, and a bright globular cluster or two. In fall, aim for the Pleiades (M45) first. In winter, the Orion Nebula (M42) is an excellent target for small scopes.

Bright, colorful double stars also make great targets. In summer, nothing beats Albireo (Beta [β] Cygni). When your child sees it or any other double, ask them what colors they see. That will help you gauge their color perception.

Posting images on social media will only build young observers' excitement, so offer to help your young observer snap a photo of the Moon. A smartphone adapter will help, but it's not crucial. And while this activity may not ultimately produce an astroimager, it's a certainty that your child will share it with their friends or use it as their wallpaper or cover photo — perhaps even inspiring other young people's interest in astronomy.

Finally, when you're back indoors, encourage your child to draw some of the objects seen through the scope. The first such sketches might be a bit fanciful, but as time goes on, they'll trend toward the real views.

It's on us

As amateur astronomers, we have an obligation to interest children — especially our own — in the night sky. To that end, I have selected six child-appropriate scopes, seen throughout this article. As you read about each, remember that children are our hobby's future. Who knows what benefits your investment of time, patience, and just a little money will yield? I'm pretty sure that you'll have fun finding out.

Michael E. Bakich *is a contributing editor of* Astronomy*.*

ORION FUNSCOPE 76MM

COURTESY OF ORION TELESCOPES

The FunScope 76mm is a 3-inch reflector that comes preassembled on its wood base. Orion includes two eyepieces, a 2x Barlow lens, a red dot finder scope, and the company's *MoonMap 260* booklet (usually priced at $12.99), a great tool to help young observers identify features on our nearest celestial neighbor. Like Celestron's FirstScope, this is a tabletop unit, so make sure you place it on a firm base. The FunScope also weighs less than 4 pounds (1.8 kilograms), so it's easy to carry and set up.

SPECIFICATIONS

Optical design: Newtonian reflector
Mount: Dobsonian
Aperture: 3 inches (76 mm)
Focal length: 300mm
Focal ratio: f/3.9
Eyepieces: 20mm (15x) and 6mm (50x)
Weight: 3.7 pounds (1.6 kg)

EXPLORE ONE AURORA II 114MM

COURTESY OF EXPLORE SCIENTIFIC

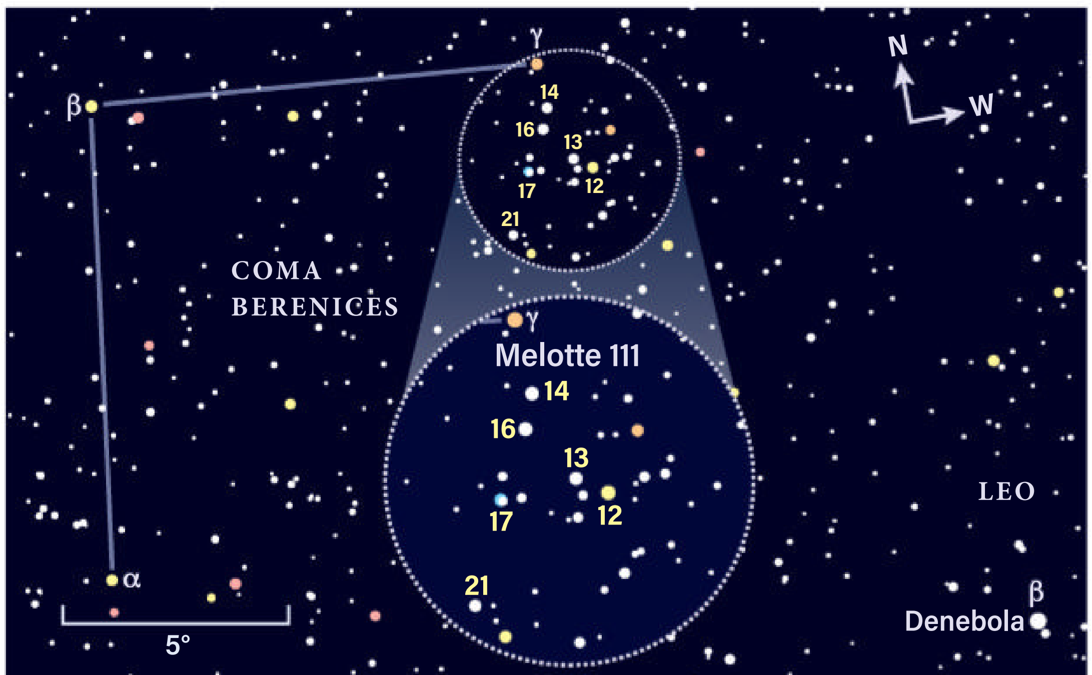
The Aurora II 114mm is a 4½-inch reflector, the largest scope in this list. The unit sits atop a fully adjustable tripod that has an accessory tray. Such a tray allows you to store extra eyepieces, but it also provides added stability. Slow-motion controls help keep objects centered in the field of view. The scope also comes with two eyepieces and a red dot finder.

SPECIFICATIONS

Optical design: Newtonian reflector
Mount: Alt-azimuth
Aperture: 4.5 inches (114 mm)
Focal length: 500mm
Focal ratio: f/10
Eyepieces: 26mm (19x) and 9.7mm (52x)
Weight: 6.3 pounds (2.86 kg)

A hair-raising cluster

Binocular users can make the most of this cluster.



The Coma Star Cluster once represented the tail of Leo, before Ptolemy III renamed it for Queen Berenice II's sacrifice of hair.
ASTRONOMY: ROEN KELLY

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

I'll admit it: I am an addict. I am hooked on vintage astronomy books. One of my favorites is *Astronomy With an Opera-Glass* by Garrett P. Serviss, first published in 1888. Serviss, a newspaper reporter by trade, was a prolific author of the late 19th and early 20th century. He wrote nine astronomy books for backyard stargazers, as well as six lesser-known science-fiction books. His words describing this month's target are a perfect way to introduce one of my favorite springtime sights:

"The three [stars], Denebola, Spica, and Arcturus, mark the corners of a great equilateral triangle. Nearly on a line between Denebola and Arcturus, and somewhat nearer to the former, you will perceive a curious twinkling, as if gossamers spangled with dew-drops were entangled there. This is the little constellation called Berenice's Hair."

Historically, Berenice II was queen of Egypt, married to Ptolemy III Euergetes. Around 240 B.C., after her husband left to fight a particularly dangerous battle against the Seleucid Empire in western Asia, Berenice vowed to the goddess Aphrodite that if Ptolemy returned safely from battle, she would cut off her flowing hair and place it in the goddess' temple. He did, so she did. But the hair mysteriously disappeared. Thinking quickly on his feet, their court astronomer Conon calmed the royal couple by pointing toward a hazy glow in the sky between Denebola and Arcturus. He announced that the mist seen faintly by eye was actually Berenice's hair, transformed by Aphrodite and placed among the stars.

Berenice's Hair, more formally known as Coma Berenices, is a faint constellation by eye, composed of only three modest naked-eye stars set in a right triangle. But what catches our eyes under darker skies is also a faint glow west of those stars. No, that misty glow is not the transfigured tresses of the ancient queen's hair. That glow is actually an open star cluster lying 280 light-years from Earth.

The **Coma Star Cluster**, known more formally as Melotte 111, often goes unnoticed through telescopes but is perfect for binoculars. That's because the cluster spans 5° of sky, far more than a telescope can drink in at once. Its stars are also quite scattered, making it difficult to appreciate the cluster even with a careful telescopic scan.

According to *Star Clusters* by Brent Archinal and Steven Hynes (Willmann-Bell, 2003), over 270 stars populate the Coma Star Cluster. Of those, about 40 shine brighter than 10th magnitude. Many are easily within range of pocket binoculars and a half-dozen even break the naked-eye barrier under dark skies.

Although I can't make out individual stars by eye from my suburban backyard, I do get a "mystical" sense to the east of Denebola (Beta [β] Leonis). When I raise my old 7x50 wide-field binoculars its way, the Coma Star Cluster immediately pops into view. Although it is not as jam-packed with stars as some open clusters in the summer or winter skies, this is always one of my first stops when I head out this time of year.

The first thing that strikes me is the cluster's distinctive shape. Those five brightest stars are arranged in arcs and lines that collectively remind me of a V-shaped skein of northward-flying geese. Others see a lowercase Greek lambda (λ) or an inverted V.

This is always one of my first stops when I head out this time of year.

The cluster's brightest star is not **Gamma (γ) Comae Berenices**, despite its prominent position at the northern edge of the cluster. Although it adds some color to the scene, Gamma, an orange type K star, lies in the foreground 170 light-years away. The brightest true cluster stars include 12, 13, 14, 16, and 21 Comae Berenices.

Several stellar pairings highlight the Coma Cluster. Of these, **17 Com**, just east of the cluster's center, is the most striking. Even the smallest opera glass will have no trouble resolving 17's 7th-magnitude companion, found 2.5' to its west-southwest.

Do you have a favorite star cluster or some other binocular target that you enjoy revisiting? Drop me a line in care of my website, philharrington.net, and tell me about it.

Until next month, remember that two eyes are better than one.

BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT **www.Astronomy.com/Harrington**

INDEX *of* ADVERTISERS

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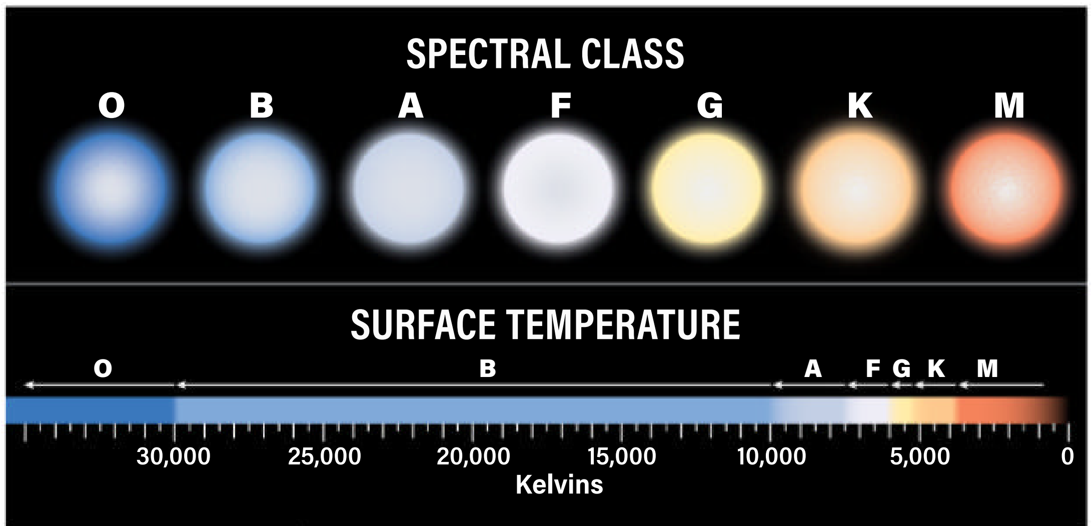
Color-coding stars

Learn the alphabet for stellar temperatures.



Stars are typically categorized by spectral class based on their colors, which are directly correlated to their temperatures. *ASTRONOMY*: ROEN KELLY

This month, we'll talk about the relationship between a star's spectral class and its color. But first, I have a question for you: Which constellation has the most stars of spectral class K9? The answer will appear later in this column.

Spectral class is the primary way stars are categorized. There are seven major classes, based on the star's surface temperature. Arranged from hottest to coolest, they are identified by the capital letters O, B, A, F, G, K, and M, remembered by the mnemonic "Oh Be A Fine Girl/Guy Kiss Me." (But that's a little outdated, so try to come up with your own and share it with us!) Each class is further divided into subgroups numbered from 0 to 9, ranging from hottest to coolest. For example, spectral class K9 is hotter than M0, but cooler than K8. A star's spectral class also indicates its color. O-, B-, and A-type stars appear blue to bluish white to white. F- and G-type stars give off faint to rich yellow hues, while K- and M-type stars appear orange to red-orange.

The following stars, all plotted on our Star Dome map (see page 34), run the gamut of spectral groups and are all visible on an early April evening. Check them out, preferably with binoculars, and note what colors you see.

Color	Star	Spectral Class
O	Meissa (Lambda [λ] Orionis)	O8
B	Regulus (Alpha [α] Leonis)	B7
A	Denebola (Beta [β] Leonis)	A3
F	Procyon (Alpha [α] Canis Minoris)	F5
G	Capella (Alpha [α] Aurigae)	G5*
K	Alphard (Alpha [α] Hydrae)	K3
M	Betelgeuse (Alpha [α] Orionis)	M2

*actually a binary system with stars of spectral classes G1 and G8.

BY GLENN CHAPLE
Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

The color contrast between stars of differing spectral classes is much easier to detect when they are close enough to compare side-by-side. Pollux (Beta [β] Geminorum) — a star of spectral class K0 — is distinctly yellow-orange when compared to pure white Castor (Alpha [α] Geminorum), an A1-type star. After comparing these two, jump to F7-type Polaris (Alpha Ursae Minoris). What color do you see?

For more of a challenge, compare Mizar (zeta [ζ] Ursae Majoris) and Alkaid (eta [η] Ursae Majoris), the outermost stars in the handle of the Big Dipper. Type B3 Alkaid is nearly a full class hotter than type A2 Mizar. But does it appear bluer? Four of the remaining Big Dipper stars are spectral class A, but one is a K1 star. Find it by studying each with binoculars or a telescope.

Here's a spectral class challenge in the form of a match game. From mid-northern latitudes in April, the constellation Corvus appears above the southern horizon during early evening. Its five brightest stars form a sail-shaped asterism called Spica's Spanker. I've listed them in the left-hand column below. In the right-hand column are their spectral classes, rearranged from hottest to coolest. Check each star with binoculars or a telescope and see if you can match it to its spectral class.

Alchiba (Alpha [α])	**B8**
Kraz (Beta[β])	**A0**
Gienah (Gamma [γ])	**F0**
Algorab (Delta [δ])	**G5**
Minkar (Epsilon [ε])	**K2**

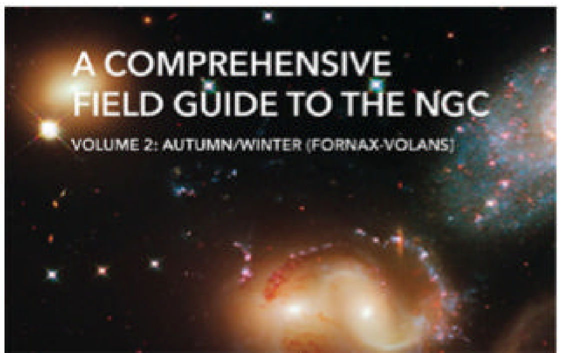
Now back to our opening question: Which constellation has the most stars of spectral class K9? It's a four-way tie between Canis Major (the Big **Dog**), Canis Minor (the Little **Dog**), Canes Venatici (the Hunting **Dogs**), and Vulpecula (the **Fox**). *All* of these stars are K9 (canine)!

All right, stop the groaning. It's April and I couldn't resist a little April Fool's fun. To be Sirius — I mean serious — the idea for this column came from an email sent by Hong Kong resident Michael Sloboda to Phil Harrington and myself. He noted that an online search turned up plenty of examples of stars of spectral classes K0 through K7, but practically no K8 or K9 stars. Why?

Unlike the other K-type stars mentioned earlier in this article, which are luminous giants, the typical star of spectral class K is an orange dwarf — a main sequence star that's cooler, less massive, and intrinsically fainter than the Sun. If you were to study a list of the brightest stars, late K-type stars would be virtually nonexistent. But look at a list of the nearest stars, and you'll find the occasional K8 or K9 star.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: choosing an ideal observing site. Clear skies!

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple**



Deep-sky guide

PDX Astronomy
Portland, Oregon

Bhavesh Parekh has produced *A Comprehensive Field Guide to the NGC*. This four-volume set contains more than 650 folio-size pages and 7,047 large images captured by the Sloan Digital Sky Survey. The spiral-bound books contain charts that are printed to match the view through a Newtonian reflector.

$125 for volumes 1 and 2 or 3 and 4; $225 for all four
pdxastronomy@gmail.com
www.pdxastronomy.com

Attention, manufacturers: To submit a product for this page, email **products@astronomy.com**.

3.1-inch refractor

Stellarvue
Auburn, California

Stellarvue's SVX080T-R Limited Edition telescope is a 3.15-inch f/6 apochromatic refractor with a 480-millimeter focal length. The three-element lens is fully multicoated and features a center element made from Ohara FPL-53 glass. The scope comes with a 2.5" focuser, dual mounting rings, and a carry case.

$1,795
530.823.7796
www.stellarvue.com

Orrery

Armstrong Metalcrafts
Albany, Oregon

Armstrong Metalcrafts' Miniature Inner Planet Orrery shows Mercury, Venus, Earth, the Moon, and Mars. It measures 4 inches (10.2 centimeters) across and is driven by a knob at its base. The main plate displays the names of the months, zodiacal symbols, and representations of the zodiacal constellations.

$495
541.924.9419
www.armstrongmetalcrafts.com

Sirius is a binary star system, home to Sirius A (left), a main sequence star, and Sirius B (right), a white dwarf. Eventually, Sirius B will cool enough that it no longer gives off visible light, becoming a black dwarf. The same fate awaits the Sun trillions of years in the future. NASA, ESA AND G. BACON (STSCI)

Earth's ultimate fate

Q IS IT SAFE TO SAY EARTH WILL BE LONG GONE BY THE TIME OUR STAR REACHES ITS FINAL STAGE: A BLACK DWARF?

Andrew Nemec
Palm Coast, Florida

A It's hard to say. After the Sun exhausts the hydrogen in its core, it will balloon into a red giant, consuming Venus and Mercury. Earth will become a scorched, lifeless rock — stripped of its atmosphere, its oceans boiled off. Astronomers aren't sure exactly how close the Sun's outer atmosphere will come to Earth. If it comes too close, friction between Earth and the outer layers of the Sun will slow our planet's orbit, causing it to slowly spiral into our star, dissolving like a sugar cube in a hot cup of coffee.

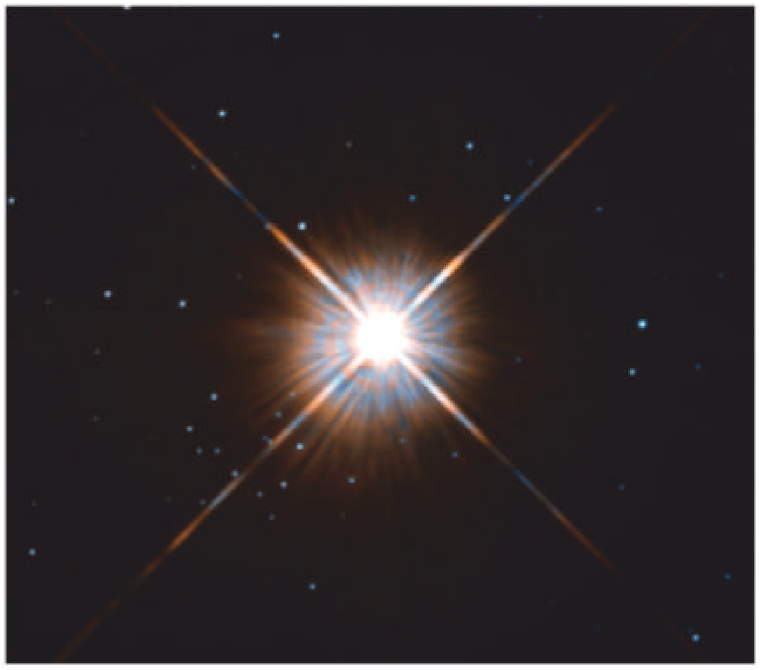
If Earth manages to survive the Sun's giant phase, it will find itself orbiting a hot white dwarf barely larger than our planet. For eons, Earth will continue to orbit the Sun. But, eventually, as the Sun cools and dims to a black dwarf, Earth's orbit will decay due to the emission of gravitational waves. Over a trillion trillion years, our once-blue planet will spiral into the dead Sun — a grand finale as the solar system goes dark forever.

The Sun doesn't have the final say in what happens to Earth, however. While the Sun won't become a red giant for another 5 billion years, a lot can happen in that time. Gravity keeps the planets in orbit around the Sun, but it also attracts the planets to each other. Although much smaller than the Sun's pull, these forces between planets tweak their orbits over millions of years, making them flex and drift. It's possible that these flexing orbits could cause the solar system to destabilize and eject planets, Earth included.

Alternatively, while other stars typically stay light-years away from the solar system, it's possible one could drift nearby in the next few billion years. The solar system may be a well-choreographed waltz of planets, but the galaxy is more like a rock concert where the stars mosh in a circle. The gravity of even a small star (or black hole) could ruin orbits and kick out planets if it gets too close. Thankfully, the odds of that happening are pretty low because there is so much space in between stars.

The ultimate fate of Earth is something only time can tell. The one thing astronomers are certain of is that any far-future inhabitants of our solar system won't want to be around to find out!

Matt Caplan
Assistant Professor of Physics, Illinois State University, Normal, Illinois



Our closest neighbor, Proxima Centauri, shines brightly in this Hubble image. Just one-eighth the mass of the Sun, Proxima Centauri is a red dwarf. ESA/HUBBLE & NASA

Q | DO RED DWARF STARS GO THROUGH THE SAME LIFE CYCLE AS STARS LIKE THE SUN, OR IS THEIR PROCESS DIFFERENT?

Steve White
Burnaby, British Columbia

A | While both red dwarfs and stars like the Sun (solar-type stars) begin and end their lives similarly, their paths diverge during the intermediate stages.

A few million years after their birth, a star's central core reaches a temperature high enough to support sustained nuclear reactions, generating energy by fusing hydrogen into helium. During this phase of evolution, red dwarfs and solar-type stars behave relatively similarly. One major difference is that red dwarfs are much dimmer and hoard their nuclear fuel over longer spans of time. So, while a solar-type star can burn hydrogen for only about 10 billion years, some red dwarfs can do so for trillions of years.

But, as the stars grow older and eventually exhaust their hydrogen fuel, changes between their life cycles begin to show. At this stage, solar-type stars grow into red giants, becoming much brighter, larger, and somewhat cooler (hence their red appearance). In contrast, red dwarfs remain small in radius but become slightly brighter and hotter (appearing blue). Another key difference is that stars like the Sun can successfully burn helium into carbon and oxygen, whereas small stars cannot and are left with a largely helium composition after exhausting their hydrogen supply.

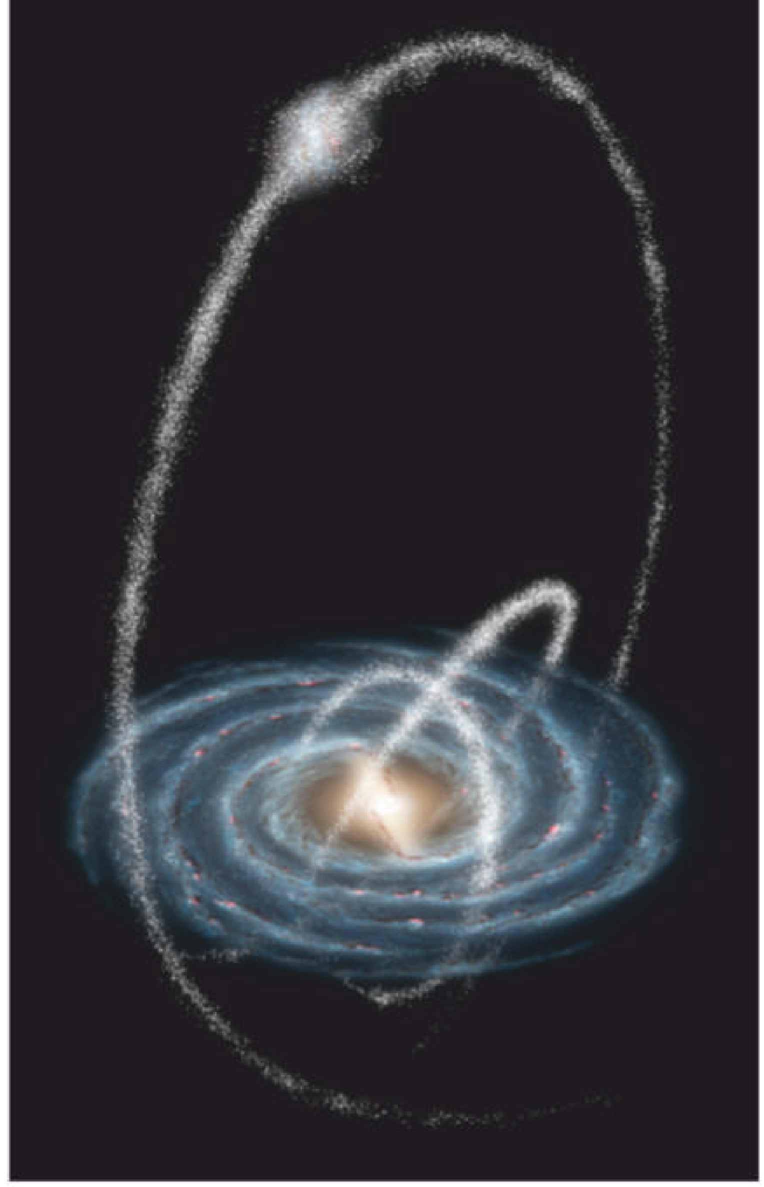
Despite these differences, the endgame is similar for both types of stars. After all of the possible nuclear reactions have been carried out, both types of stars end their lives as white dwarfs. The solar-type stars blow off much of their original mass and are composed primarily of carbon and oxygen as they condense into white dwarfs. Red dwarfs retain most of their original mass and become white dwarfs composed primarily of helium. Regardless of their composition, these stellar remnants no longer actively generate energy via nuclear processing. Instead, they shine with the residual energy left over from their previous epochs of stardom.

Fred Adams
Professor of Physics, University of Michigan, Ann Arbor, Michigan

Q | IS THE DARK MATTER SHAPE OF THE MILKY WAY THE SAME AS THE LUMINOUS MATTER SHAPE?

Jack Kessler
Walnut Creek, California

A | Determining where dark matter lies is a difficult task, since we cannot observe it directly. Astronomers can only infer its presence from the motions of stars in the galaxy, which makes it difficult to determine a precise shape. Comparatively, it's pretty easy to figure out how stars within the Milky Way Galaxy are distributed (i.e., most are in a disk), since we can observe them.



Streams of stars ripped from a companion galaxy circle the Milky Way in this artist's concept. By looking at similar streams from the Sagittarius Dwarf Galaxy, astronomers were able to piece together our galaxy's dark matter shape. NASA/JPL-CALTECH/R. HURT (SSC/CALTECH)

One of the most accurate ways to determine the dark matter shape of a galaxy is to trace the motion of satellite galaxies as they orbit their host galaxy. This is easiest to do for satellite galaxies that have been torn apart by the host galaxy. One of the most famous for the Milky Way is the Sagittarius Dwarf Galaxy. Some 70,000 light-years away, Sagittarius' bundle of stars has been shredded and stretched into a thin stream of stars around the Milky Way. While the orbits of other, less-disrupted galaxies and star clusters may seem ideal for measuring the distribution of dark matter in the Milky Way, their timetables are much too slow for human lifetimes. But streams like Sagittarius have their recent orbits drawn into their shape.

The latest models of Sagittarius and other streams suggest that the Milky Way's dark halo has a shape that changes depending on the distance from the center of the galaxy. In the inner regions, close to the disk, the dark matter halo appears to be a flattened sphere, like a football, with the long axis pointing in the direction of the disk. But as one moves outwards, the halo flips so the football is balanced on one of its points as the galaxy swirls around it.

So, in summary, the answer to the question is: No, the dark matter and the luminous matter have rather different shapes.

Amina Helmi
Astronomer, University of Groningen, Groningen, Netherlands

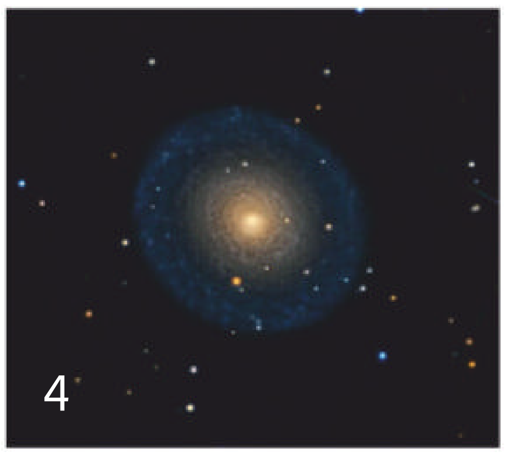
SEND US YOUR QUESTIONS

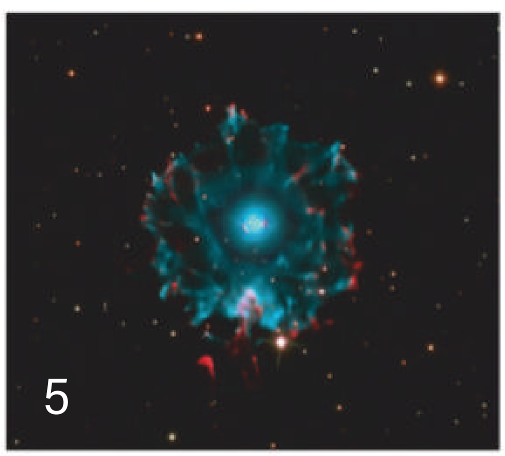
Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

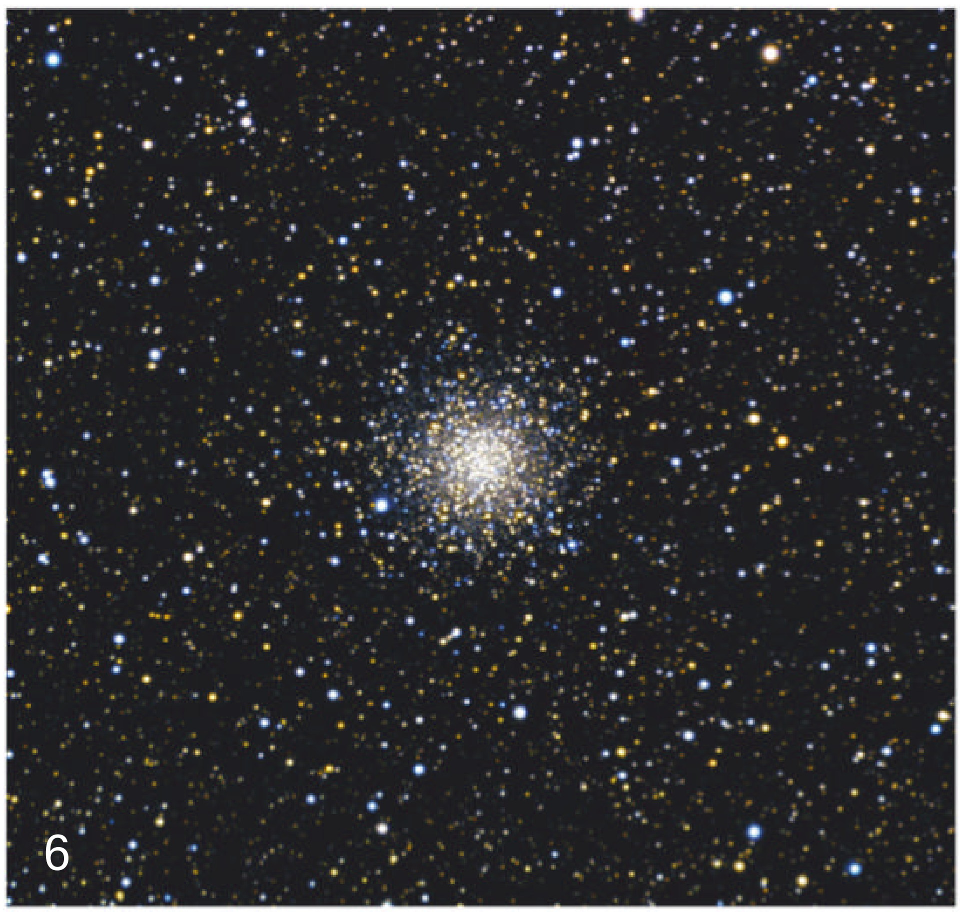
Cosmic portraits

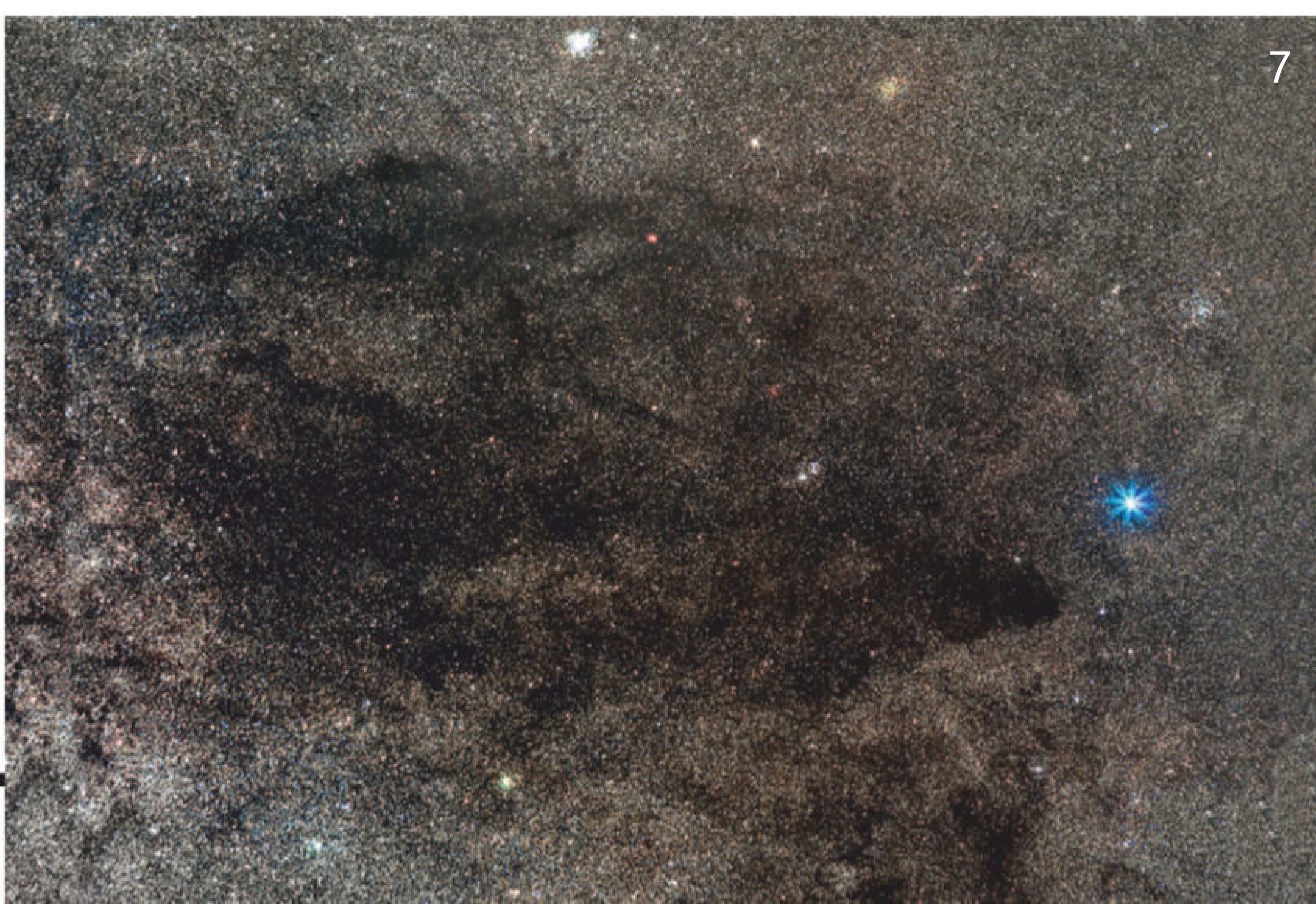
1. SEVEN SISTERS SOUTH
The Southern Pleiades (IC 2602), also known as the Theta Carinae Cluster, is the third-brightest open cluster in the sky. It shines at magnitude 1.9 and covers an area 50' across. It lies some 550 light-years away in the constellation Carina the Keel. • ***Nicholas Clarke***

2. DARKNESS OVER LIGHT
This image shows the full extent of the Great Rift through Cygnus to the Elephant Trunk Nebula at the bottom left. Note the complete Veil Nebula at right. This 31-image mosaic is the result of 258 hours of exposures collected through Hydrogen-alpha, Sulfur-II, and Oxygen-III filters. • ***Alistair Symon***









3. AHEAD OF THE CURVE
The Crescent Nebula (NGC 6888) floats within a vast region of glowing gas made even more apparent because the exposures used to create this image came through Hydrogen-alpha, Sulfur-II, and Oxygen-III filters. The Crescent lies in the constellation Cygnus the Swan about 5,000 light-years away. • ***Greg Gurdak***

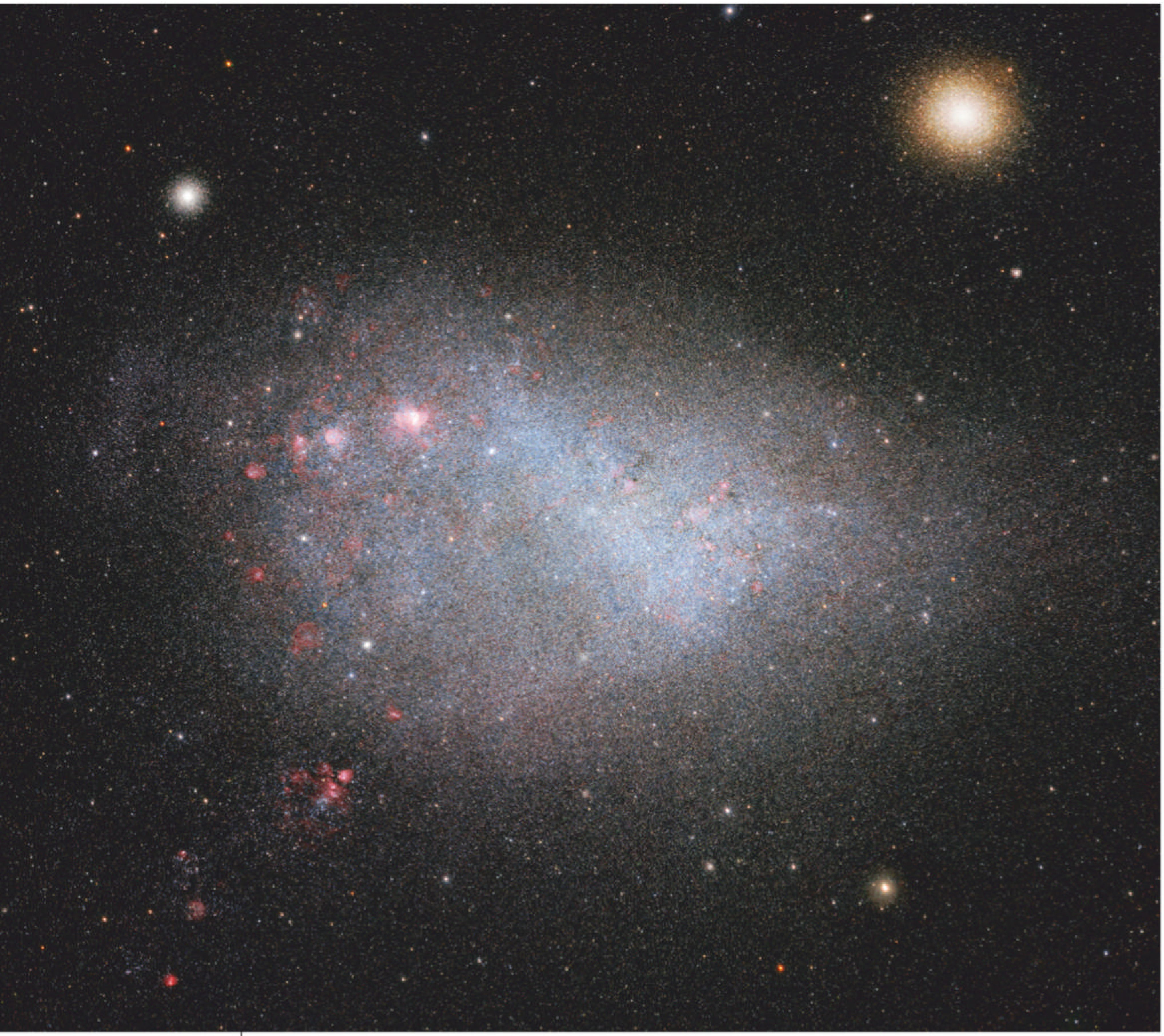
4. WITH THIS RING ...
NGC 7217 is a gorgeous ring galaxy in Pegasus. It glows at magnitude 10.1 and lies 50 million light-years away. Because some stars orbit the galaxy's center in a direction opposite others, astronomers think a massive collision formed the ring.
• ***Lefteris Velissaratos***

5. MEOW
The Cat's Eye Nebula (NGC 6543) glows slightly brighter than 10th magnitude in the northern constellation Draco the Dragon. It lies about 3,400 light-years from Earth. The expanding sphere of gas is moving into space at a speed of 4.25 million mph (6.8 million km/h). • ***Tony Hallas***

6. OVER HERE!
Globular cluster M56 is often overlooked by observers who are more interested in the Ring Nebula (M57), which also lies in Lyra. M56 lies 33,000 light-years away and glows at magnitude 8.3. Astronomers estimate that it has a mass of 230,000 suns.
• ***Rod Pommier***

7. AS DARK AS NIGHT
The Coalsack is a dark nebula — a cloud of dust and cold gas — mainly in the southern constellation Crux the Cross, although some of it touches Centaurus and Musca. It lies some 600 light-years away and covers an area of sky 7° by 5°. • ***Fernando Oliveira de Menezes***

SEND YOUR IMAGES TO:
Astronomy Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@ astronomy.com.**



STARBIRTH RUNS WILD IN NEARBY GALAXY

For a dwarf galaxy, the Small Magellanic Cloud (SMC) punches well above its weight. Most such galaxies have long since exhausted the hydrogen needed to create stars, but each of the reddish clouds sprinkled across this satellite of the Milky Way harbors hundreds or thousands of newborn suns. Astronomers suspect a recent collision with its bigger neighbor, the Large Magellanic Cloud, triggered the outburst. Scientists recorded the SMC with the 4-meter Victor M. Blanco Telescope on Cerro Tololo in Chile as part of the Survey of the MAgellanic Stellar History (SMASH). The portrait also captured the sky's second-brightest globular cluster, 47 Tucanae, to the SMC's upper right, as well as the smaller but still impressive globular NGC 362 to the galaxy's upper left. CTIO/NOIRLAB/NSF/AURA/SMASH/D. NIDEVER (MONTANA STATE UNIVERSITY)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Milky Way at Stellarvue Dark Sky Star Party. Image by Tony Hallas.

June 2021

Giant worlds on fine display

The brightest planet lurks low in the northwest after sunset all month. **Venus** gleams at magnitude –3.9 and stands out despite the competition from evening twilight. The planet lies only 7° high a half-hour after sunset in early June, but it is on a path that takes it away from our star and into a darker sky. By month's end, the brilliant object appears 15° high at the same time.

Venus currently lies on the far side of the Sun from Earth and thus looks tiny through a telescope. Even at month's end, our sister planet spans just 11" and shows a 90-percent-lit phase. Far better views await us this spring.

If you are blessed with an unobstructed horizon toward the northwest, you might also glimpse **Mercury** through binoculars in early June. The innermost planet lies 4° to Venus' lower left on the 1st. Mercury glows dimly at magnitude 2.9, however, so you'll need an exceptionally clear sky to spot it.

The planet disappears in the solar glare a few days later as it heads toward inferior conjunction June 11. It then emerges in the northeast before dawn late in the month. On the 30th, Mercury shines at magnitude 1.0 and stands 12° high 30 minutes before sunup. A telescope reveals a disk that spans 9" and appears one-quarter lit.

Back in the evening sky, the ruddy glow of **Mars** continues to grace the northwestern sky after darkness falls. The 2nd-magnitude Red Planet appears in eastern Gemini in early June, when you can find it due south (upper left) of the Twins' brightest stars, Castor and Pollux. Mars drifts eastward as the month progresses and passes into Cancer the Crab on the 8th. Don't miss its crossing of the Beehive star cluster (M44) on the 23rd and 24th. Binoculars will offer the best views of this splendid event. Sadly, the planet's 4"-diameter disk offers no details when viewed through a telescope.

Not long after Mars dips below the horizon, **Saturn** rises in the east. The ringed planet appears against the backdrop of Capricornus, though the planet makes a more useful guide to the constellation than vice versa. Saturn glows at magnitude 0.4, nearly 10 times brighter than the Sea Goat's brightest star.

Planetarium visitors often ask me what sort of telescope they need to see Saturn's rings. I tell them that the solar system's most spectacular sight shows up through even the smallest scopes using medium magnification. Look for yourself. This month you can see the planet's 18"-diameter disk surrounded by a ring system that spans 41" and tilts 17° to our line of sight.

Jupiter rises about 90 minutes after Saturn. Blazing at magnitude –2.5, the giant planet appears brighter than any other point of light except for Venus. Jupiter lies among the faint background stars of Aquarius the Water-bearer, one constellation east of Saturn's current home.

Point your telescope toward Jupiter and you'll see why it's a favorite of so many backyard observers. The planet's disk spans 43" in mid-June and shows up clearly through small instruments. You can spend hours viewing details in its banded atmosphere and tracking the movements of its four bright moons. For the sharpest views of Jupiter, and Saturn for that matter, wait until they climb higher in the hours after midnight.

The starry sky

June must be among the best times for stargazing, particularly for those in the Southern Hemisphere. Not only do the finest parts of the Milky Way climb high in the sky by late evening, but we also enjoy our longest nights of the year. (Our northern friends suffer through short nights with the central Milky Way hanging low.)

And contrary to popular belief, you can enjoy many of the sights with nothing more than binoculars. Breathtaking views await anyone viewing under a dark sky beginning in the early evening. Start high in the south with the pointer stars, Alpha [α] and Beta [β] Centauri, then head to the right to Crux the Cross and the magnificent star fields farther on.

Scan about two binocular fields to the Cross' right and you'll find one of the Milky Way's richest parts. The highlights here include the Eta (η) Carinae region and open cluster NGC 3532, a large, dense scattering of stars that ranks among my personal favorites.

Also look for the Emu, a conspicuous shape formed by dark dust clouds that block the Milky Way's glow. Its head nestles in the lower left part of Crux and its body extends to the lower left all the way to the tail of Scorpius the Scorpion. While watching the Scorpion climb, aim your binoculars below the Stinger and you'll find two outstanding Messier objects: the open star clusters M6 and M7.

As evening progresses, the full extent of Sagittarius the Archer comes into view in the east. We are now looking toward the center of the Milky Way Galaxy, where a throng of fine binocular sights awaits. I sometimes try to forget how well I know the sky and simply scan this area, stopping on each cluster or fuzzy object.

This region climbs nearly overhead by midnight local time. Meanwhile, Crux appears prominent in the southwest. If you continue stargazing through the night, the Cross dips low in the south as morning twilight starts to paint the sky. And for viewers north of about 27° south latitude, the constellation even sinks completely below the horizon.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. June 1
8 P.M. June 15
7 P.M. June 30

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

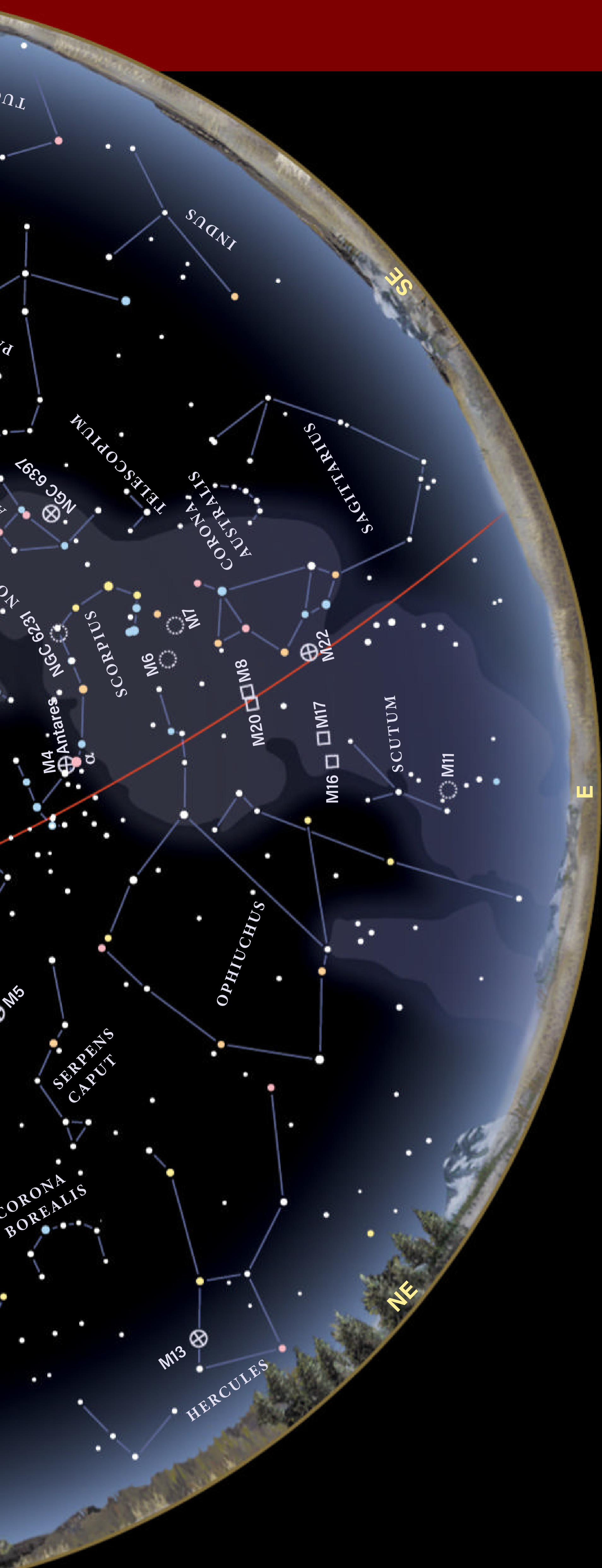
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



JUNE 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 The Moon passes 5° south of Jupiter, 9h UT

2 Last Quarter Moon occurs at 7h24m UT

Mars passes 5° south of Pollux, 14h UT

3 The Moon passes 4° south of Neptune, 1h UT

6 Asteroid Juno is at opposition, 22h UT

7 The Moon passes 2° south of Uranus, 6h UT

8 The Moon is at apogee (406,228 kilometers from Earth), 2h27m UT

10 New Moon occurs at 10h53m UT

11 Mercury is in inferior conjunction, 1h UT

12 The Moon passes 1.5° north of Venus, 7h UT

13 The Moon passes 3° north of Mars, 20h UT

18 First Quarter Moon occurs at 3h54m UT

21 Winter solstice occurs at 3h32m UT

Jupiter is stationary, 5h UT

22 Venus passes 5° south of Pollux, 15h UT

Mercury is stationary, 23h UT

23 The Moon is at perigee (359,956 kilometers from Earth), 9h55m UT

24 Full Moon occurs at 18h40m UT

26 Neptune is stationary, 10h UT

27 The Moon passes 4° south of Saturn, 9h UT

28 The Moon passes 4° south of Jupiter, 19h UT

30 The Moon passes 4° south of Neptune, 9h UT